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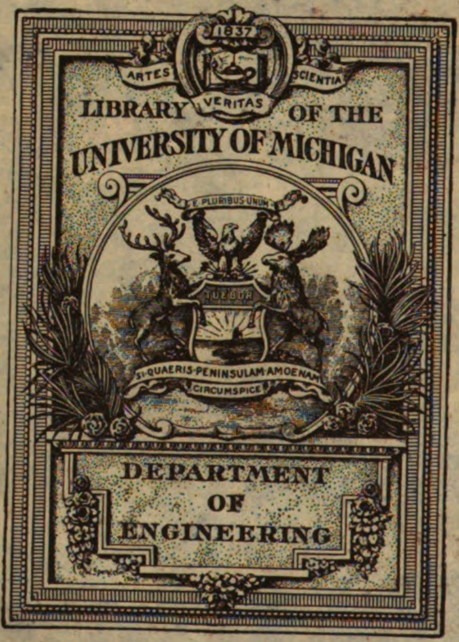

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INSTITUTION

OF

MECHANICAL ENGINEERS.

PROCEEDINGS.

1867.

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81 *Newhall Street, Birmingham.*

LIST OF MEMBERS,

WITH YEAR OF ELECTION.

1867.

MEMBERS.

1861. Abel, Charles Denton, 20 Southampton Buildings, London, W.C.
1865. Adams, William, Locomotive Superintendent, North London Railway, Bow, London, E.
1848. Adams, William Alexander, Newbold Beeches, Leamington.
1859. Adamson, Daniel, Newton Moor Iron Works, Hyde, near Manchester.
1861. Addenbrooke, George, Rough Hay Furnaces, Darlaston, near Wednesbury.
1851. Addison, John, 6 Delahay Street, Westminster, S.W.
1858. Albaret, Auguste, Engine Works, Liancourt, Oise, France.
1847. Allan, Alexander, Bridge Street, Worcester.
1865. Allen, William Daniel, Bessemer Steel Works, Sheffield.
1865. Alleyne, John Gay Newton, Butterley Iron Works, Alfreton.
1867. Allibon, George, Worcester Engine Works, Worcester.
1859. Alton, George, Midland Road, Derby.
1861. Amos, Charles Edwards, 5 Cedars Road, Clapham Common, London, S.W.
1867. Amos, James Chapman, Grove Works, Southwark Street, London, S.E.
1856. Anderson, John, Superintendent of Machinery to the War Department, Royal Arsenal, Woolwich, S.E.
1856. Anderson, William, Erith Iron Works, Erith, Kent, S.E.
1862. Angus, Robert, Locomotive Superintendent, North Staffordshire Railway, Stoke-upon-Trent.
1858. Appleby, Charles Edward, Renishaw Iron Works, near Chesterfield.
1867. Appleby, Charles James, Emerson Street, Southwark, London, S.E.
1859. Armitage, William James, Farnley Iron Works, Leeds.
1866. Armstrong, George, Great Western Railway, Locomotive Department, Wolverhampton.
1863. Armstrong, John, Timber Works, 17 North Bridge Street, Sunderland.
1857. Armstrong, Joseph, Locomotive Superintendent, Great Western Railway, Swindon.
1858. Armstrong, Sir William George, Elswick, Newcastle-on-Tyne.
1857. Ashbury, James Lloyd, 9 Sussex Place, Hyde Park Gardens, London, W.

1865. Bagshawe, John J., Thames Steel Works, Sheffield.

1865. Bailey, John, Blackhall Place Iron Works, Dublin.

1860. Bailey, Samuel, Mining Engineer, The Pleck, near Walsall.

1866. Baines, William, London Works, Soho, near Birmingham.

1866. Baker, Samuel, 22 Oil Street, Liverpool.

1865. Baldwin, Martin, Bovereux Iron Works, Bilston.

1860. Barclay, John, Bowling Iron Works, near Bradford, Yorkshire.

1865. Barclay, William, 4 College Lane, Liverpool.

1866. Barker, George, Messrs. Barker and Cope, Kidsgrove, Stoke-upon-Trent.

1860. Barker, Paul, Old Park Iron Works, Wednesbury.

1866. Barnard, Clement, 2 Staples Inn, Holborn, London, W.C.

1862. Barrow, Joseph, Whalley Chambers, 88 King Street, Manchester.

1867. Barrows, Thomas Welch, Portable Engine Works, Banbury.

1862. Barton, Edward, Carnforth Hæmatite Iron Works, Carnforth, near Lancaster.

1865. Bass, William, Sanitary Pipe Works, Parkgate, near Rotherham.

1860. Batho, William Fothergill, 36 Lancaster Street, Birmingham.

1859. Beacock, Robert, Victoria Foundry, Leeds.

1865. Beardshaw, Charles C., Baltic Steel Works, Sheffield.

1848. Beattie, Joseph, Locomotive Superintendent, London and South Western Railway, Nine Elms, London, S.W.

1867. Beaumont, Captain Frederick, R.E., Royal Engineer Office, Sheerness.

1859. Beck, Edward, Messrs. Neild and Co., Dallam Iron Works, Warrington. (*Life Member.*)

1862. Beckett, Henry, Mining Engineer, Upper Penn, Wolverhampton.

1864. Beckton, James George, Whitby, Yorkshire.

1865. Bell, Charles, North Staffordshire Railway, Locomotive Department, Stoke-upon-Trent.

1867. Bell, George, Soho Iron Works, Bolton.

1858. Bell, Isaac Lowthian, Clarence Felling and Wylam Iron Works, Newcastle-on-Tyne.

1865. Bell, John, Belmont House, Timperley, near Manchester.

1857. Bellhouse, Edward Taylor, Eagle Foundry, Hunt Street, Oxford Street, Manchester.

1865. Bennett, Henry, Wombridge Iron Works, near Wellington, Shropshire.

1854. Bennett, Peter Duckworth, Spon Lane Iron Foundry, Westbromwich.

1865. Benson, George Henry, Stalybridge.

1867. Berkley, George, 24 Great George Street, Westminster, S.W.

1867. Bernhardt, George, Stand Lane, Radcliffe, near Manchester.

1861. Bessemer, Henry, 4 Queen Street Place, New Cannon Street, London, E.C.

1866. Bevis, Restel Ratsey, Birkenhead Iron Works, Birkenhead.

1847. Beyer, Charles F., Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1861. Binns, Charles, Mining Engineer, Clay Cross, near Chesterfield.

1863. Birckel, John James, Regent's Canal Iron Works, Eagle Wharf Road, London, N.

1866. Birkbeck, John Addison, Sheepbridge Iron Works, Chesterfield.

1847. Birley, Henry, Haigh Foundry, near Wigan.

1856. Blackburn, Isaac, Witton Park Iron Works, Darlington.

1851. Blackwell, Samuel Holden, Dudley.

1865. Bladen, Charles, Provan Mill House, Springburn, near Glasgow.

1862. Blake, Henry Wollaston, Messrs. James Watt and Co., 18 London Street, London, E.C.

1867. Bleckly, John James, Bewsey Iron Works, Warrington.

1862. Blyth, Alfred, Steam Engine Works, Fore Street, Limehouse, London, E.

1863. Boeddinghaus, Julius, Messrs. Heinrich Boeddinghaus and Sons, Elberfeld, Prussia.

1862. Bouch, Thomas, 78 George Street, Edinburgh.

1858. Bouch, William, Shildon Engine Works, Darlington.

1847. Bovill, George Hinton, 24 Duke Street, Westminster, S.W.

1858. Bower, John Wilkes, Lancashire and Yorkshire Railway, Engineer's Office, Manchester. (*Life Member.*)

1862. Boyd, Nelson, Belfast Foundry, Donegal Street, Belfast.

1854. Bragge, William, Atlas Steel and Iron Works, Sheffield.

1854. Bramwell, Frederick Joseph, 37 Great George Street, Westminster, S.W.

1848. Broad, Robert, Horseley Iron Works, near Tipton.

1865. Brock, Walter, Vulcan Foundry, Glasgow.

1852. Brogden, Henry, Sale, near Manchester. (*Life Member.*)

1866. Brown, Andrew Betts, Vauxhall Iron Works, London, S.E.

1866. Brown, Charles James, Unity Chambers, Temple Street, Birmingham.

1865. Brown, George, Rotherham Iron Works, Rotherham.

1863. Brown, Henry, Metropolitan Carriage and Wagon Co., Saltley Works, Birmingham.

1847. Brown, James, Jun., Messrs. James Watt and Co., Soho Foundry, near Birmingham.

1850. Brown, Sir John, Atlas Steel and Iron Works, Sheffield.

1855. Brown, John, Mining Engineer, Barnsley.

1853. Brown, Ralph, Patent Shaft Works, Wednesbury.

1867. Bruce, William Duff, Government Engineer, Lucknow, India.

1865. Bryant, Frederick William, Blackfriars Bridge Works, Chatham Place, London, E.C.

1866. Bryham, William, Rose Bridge and Douglas Bank Collieries, near Wigan.

1858. Burn, Henry, Midland Railway, Locomotive Department, Derby.

1856. Butler, Ambrose Edmund, Kirkstall Forge, Leeds.

1863. Butler, Arthur, Surdah, Radshye, Lower Bengal, India: (or care of W. J. Butler, Chipping Hill, Witham).

1859. Butler, John, Stanningley Iron Works, near Leeds.
1859. Butler, John Octavius, Kirkstall Forge, Leeds.

1857. Cabry, Joseph, Resident Engineer, Blyth and Tyne Railway, Newcastle-on-Tyne.
1847. Cabry, Thomas, North Eastern Railway, York.
1847. Cammell, Charles, Cyclops Steel and Iron Works, Sheffield.
1867. Campbell, Daniel, 10 John Street, Adelphi, London, W.C.
1864. Campbell, David, 20 Castle Street, Liverpool.
1864. Campbell, James, Staveley Coal and Iron Works, Staveley, near Chesterfield.
1860. Cannell, Fleetwood James, Old Park Iron Works, Wednesbury.
1860. Carbutt, Edward Hamer, Vulcan Iron Works, Thornton Road, Bradford, Yorkshire.
1865. Carlton, Samuel, Great Western Railway, Locomotive Department, Swindon.
1862. Carpmael, William, 24 Southampton Buildings, London, W.C.
1866. Carpmael, William, Jun., 24 Southampton Buildings, London, W.C.
1856. Carrett, William Elliott, Sun Foundry, Leeds.
1864. Carrington, William Thomas, 10 Park Street, Westminster, S.W.
1858. Carson, James Irving, Locomotive Superintendent, West Hartlepool Harbour and Railway, Stockton-on-Tees.
1866. Chapman, Henry, 41 Boulevard Malesherbes, Paris.
1867. Chatwood, Samuel, Lancashire Safe and Lock Works, Bolton.
1857. Chrimes, Richard, Brass Works, Rotherham.
1866. Claridge, Thomas, Phœnix Foundry, near Bilston.
1859. Clark, George, Monkwearmouth Engine Works, Sunderland.
1867. Clark, George, Jun., Monkwearmouth Engine Works, Sunderland.
1862. Clark, James, Wellington Foundry, Leeds.
1867. Clark, William, Engineer to the Municipality of Calcutta, 9 Victoria Chambers, Victoria Street, Westminster, S.W.
1865. Clarke, John, Railway Foundry, Jack Lane, Leeds.
1859. Clay, William, Exchange Buildings, Liverpool.
1863. Clayton, Robert, Soho Foundry, Preston.
1866. Cleworth, Charles, Assistant Locomotive Superintendent, East Indian Railway, Jumalpore, India.
1867. Cliff, Joseph, Union Foundry, Bradford, Yorkshire.
1847. Clift, John Edward, Prospect Hill, Redditch.
1860. Clunes, Thomas, Worcester Engine Works, Worcester.
1858. Cochrane, Charles, Woodside Iron Works, near Dudley.
1860. Cochrane, Henry, Ormesby Iron Works, Middlesbrough.
1854. Cochrane, John, Woodside Iron Works, near Dudley.
1867. Cockey, Francis Christopher, Selwood Iron Works, Frome.

1864. Coddington, William, Ordnance Cotton Mill, Blackburn.
1847. Coke, Richard George, Mining Engineer, Chesterfield.
1867. Coke, William Langton, 11 Great Queen Street, Westminster, S.W.
1864. Colburn, Zerah, 7 Gloucester Road, Regent's Park, London, N.W.
1853. Cooper, Samuel Thomas, Leeds Iron Works, Leeds.
1860. Cope, James, Mining Engineer, Pensnett, near Dudley.
1865. Corlett, Henry Lee, Great Southern and Western Railway, Carriage Department, Dublin.
1848. Corry, Edward, 8 New Broad Street, London, E.C.
1857. Cortazzi, Francis James, care of Hugh Hornby, Sandown, Wavertree, Liverpool.
1860. Coulthard, Hiram Craven, Park Iron Works, Blackburn.
1864. Cowans, John, St. Nicholas and Woodbank Iron Works, Carlisle.
1847. Cowper, Edward Alfred, 6 Great George Street, Westminster, S.W.
1862. Cox, Samuel H. F., 3 East Parade, Sheffield.
1863. Craig, Andrew, 6 Cecil Place, Paisley Road, Glasgow.
1847. Crampton, Thomas Russell, 12 Great George Street, Westminster, S.W.
1866. Craven, William, Vauxhall Iron Works, Osborne Street, Manchester.
1858. Crawhall, Joseph, St. Ann's Wire and Hemp Rope Works, Newcastle-on-Tyne.
1865. Cross, James, St. Helen's Locomotive Works, St. Helen's.
1863. Crow, George, Messrs. R. Stephenson and Co., South Street, Newcastle-on-Tyne.
1864. Crowe, Edward, Tees Side Iron Works, Middlesbrough.

1864. Daglish, George Heaton, St. Helen's Foundry, St. Helen's.
1866. Daniel, Edward Freer, Abbey Iron Works, Shrewsbury.
1866. Daniel, William, 11 Blenheim Square, Leeds.
1865. Darby, Abraham, Ebbw Vale Iron Works, near Tredegar.
1864. Darby, Charles E., Brymbo Iron Works, near Wrexham.
1865. Davidson, James, Royal Arsenal, Laboratory Department, Woolwich, S.E.
1865. Davies, Benjamin, Huyton Bleach Works, near Chorley.
1863. Davy, Alfred, Park Iron Works, Sheffield.
1849. Dawes, George, Milton and Elsecar Iron Works, near Barnsley.
1860. Dawes, William Henry, Bromford Iron Works, Westbromwich.
1861. Dawson, Benjamin, South Hetton, near Fence Houses.
1866. Death, Ephraim, Albert Works, Leicester.
1857. De Bergue, Charles, Strangeways Iron Works, Manchester.
1858. Dees, James, Whitehaven.
1858. Dempsey, William, 26 Great George Street, Westminster, S.W.
1864. Dewhurst, John, Lancashire Steel Works, Gorton, Manchester.
1865. Dircks, Henry, 48 Charing Cross, London, S.W. (*Life Member.*)
1859. Dixon, John, Railway Foundry, Bradford, Yorkshire.

1865. Dobson, Benjamin, Messrs. Dobson and Barlow, Kay Street Works, Bolton.
1865. Domville, Charles Kelloch, Resident Engineer and Locomotive Superintendent, Belfast and County Down Railway, Belfast.
1865. Douglas, Charles P., Consett Iron Works, near Blackhill, County Durham.
1857. Douglas, George K., Messrs. R. Stephenson and Co., South Street, Newcastle-on-Tyne.
1857. Dove, George, St. Nicholas and Woodbank Iron Works, Carlisle.
1866. Downey, Alfred C., Ormesby Iron Works, Middlesbrough.
1847. Dubs, Henry, Glasgow Locomotive Works, Glasgow.
1857. Dunlop, John Macmillan, Holehird, Windermere.
1854. Dunn, Thomas, 52 Withington Street, Pendleton, Manchester.
1864. Dunn, Thomas Edward, Jumna Bridge, East Indian Railway, Allahabad, India: (or care of R. Dunn, Howick, Bilton, Northumberland.)
1861. Dutton, Charles, Sams Lane, Westbromwich.
1860. Dyson, George, Tudhoe Iron Works, near Ferryhill.
1865. Dyson, Robert, Phœnix Wheel Tyre and Axle Works, Rotherham.

1859. Eassie, Peter Boyd, Railway Saw Mills, Gloucester.
1858. Easton, Edward, Grove Works, Southwark, London, S.E.
1867. Easton, James, Mining Engineer, Nest House, Gateshead.
1856. Eastwood, James, Railway Iron Works, Derby.
1866. Eloe, John, Phœnix Iron Works, Manchester.
1862. Elder, John, Messrs. Randolph Elder and Co., Centre Street, Glasgow.
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1865. Elliot, Walter, Civil Engineer to the Colonial Government, Gibraltar.
1860. Elwell, Thomas, Messrs. Varrall Elwell and Poulot, 9 Avenue Trudaine, Paris.
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1864. Etienne, Antonin, 77 Calle de las Palmas, Seville, Spain.
1857. Evans, John Campbell, Arts Club, Hanover Square, London, W.
1848. Everitt, George Allen, Kingston Metal Works, Adderley Street, Birmingham.
1864. Everitt, William Edward, Kingston Metal Works, Adderley Street, Birmingham.
1865. Evers, Frank, Cradley Iron Works, near Stourbridge.

1857. Fairlie, Robert Francis, 9 Victoria Chambers, Victoria Street, Westminster, S.W.
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1865. Faviell, Samuel Clough, Clarence Iron Works, Leeds.
1866. Fenby, Joseph Beverley, 61 Pershore Road, Edgbaston, Birmingham.
1854. Fernie, John, Clarence Iron Works, Leeds.

1866. Fiddes, Walter, Engineer, Bristol United Gas Works, Bristol.

1867. Field, Edward, Chandos Chambers, Buckingham Street, Adelphi, London, W.C.

1861. Field, Joshua, 110 Westminster Bridge Road, Lambeth, London, S.E.

1865. Filliter, Edward, Resident Engineer, Leeds Water Works, 16 East Parade, Leeds.

1864. Fleet, Thomas, Crown Boiler Works, Westbromwich.

1861. Fleetwood, Daniel Joseph, 58 Broad Street, Birmingham.

1847. Fletcher, Edward, Locomotive Superintendent, North Eastern Railway, Gateshead.

1858. Fletcher, Henry Allason, Lowca Engine Works, Whitehaven. (*Life Member.*)

1857. Fletcher, James, Messrs. W. Collier and Co., 2 Greengate, Salford, Manchester.

1866. Fletcher, James, Jun., Messrs. W. Collier and Co., 2 Greengate, Salford, Manchester.

1867. Fletcher, Lavington Evans, Association for the Prevention of Steam Boiler Explosions, 41 Corporation Street, Manchester.

1859. Fogg, Robert, 17 Park Street, Westminster, S.W.

1861. Forster, Edward, Spon Lane Glass Works, near Birmingham.

1849. Forsyth, John C., North Staffordshire Railway, Stoke-upon-Trent.

1864. Foster, Edward Henry, Old Park Hall, Walsall.

1861. Foster, Sampson Lloyd, Old Park Iron Works, Wednesbury.

1847. Fothergill, Benjamin, 139 Cannon Street, London, E.C.

1866. Fowler, George, Mining Engineer, Ashby-de-la-Zouch.

1847. Fowler, John, 2 Queen Square Place, Westminster, S.W.

1847. Fox, Sir Charles, 8 New Street, Spring Gardens, London, S.W.

1866. Fox, Charles Douglas, 8 New Street, Spring Gardens, London, S.W.

1859. Fraser, John, 18 York Place, Leeds.

1866. Fraser, John Simpson, Carriage and Wagon Superintendent, Great Western Railway, Paddington, London, W.

1856. Freeman, Joseph, 98 Cannon Street, London, E.C.

1864. Frost, Thomas, Wadsley Bridge Iron and Steel Works, near Sheffield.

1852. Froude, William, Elmsleigh, Paignton, Torquay.

1866. Fry, Albert, Bristol Wagon Works, Temple Gate, Bristol.

1865. Gainsford, William Dunn, Sheffield Coal Co., Sheffield.

1866. Galloway, Charles John, Knott Mill Iron Works, Manchester.

1862. Galton, Capt. Douglas, R.E., War Office, Pall Mall, London, S.W.

1847. Garland, William S., Messrs. James Watt and Co., Soho Foundry, near Birmingham.

1867. Gauntlett, William Henry, Furness Iron and Steel Works, Dalton-in-Furness.

1848. Gibbons, Benjamin, Hill Hampton House, near Stourport.
1856. Gilkes, Edgar, Tees Engine Works, Middlesbrough.
1866. Gilroy, George, Engineer, Ince Hall Colliery, Wigan.
1862. Godfrey, Samuel, Messrs. Bolckow and Vaughan's Iron Works, Middlesbrough.
1867. Gooch, William Frederick, Vulcan Foundry, Warrington.
1865. Göransson, Göran Fredrick, Steel Works, Gefle and Högbo, Sweden.
1865. Gray, John McFarlane, Board of Trade Steam Ship Surveyor, Custom House, Dublin.
1861. Green, Edward, Jun., 14 St. Ann's Square, Manchester.
1867. Greenwell, George Clementson, Mining Engineer, Poynton, near Stockport.
1858. Greenwood, Thomas, Albion Works, Armley Road, Leeds.
1857. Gregory, John, Braganza Hotel, Lisbon, Portugal.
1865. Greig, David, Steam Plough and Locomotive Works, Leeds.
1866. Grice, Edwin James, Stour Valley Works, Spon Lane, Westbromwich.
1860. Grice, Frederic Groom, Stour Valley Works, Spon Lane, Westbromwich.
1866. Gurden, Charles Frederick, Superintendent Engineer, Brazil and River Plate Steam Boat Co., 43 Canning Street, Birkenhead.

1863. Hackney, William, 3 Great George Street, Westminster, S.W.
1861. Haggie, Peter, Hemp and Wire Rope Works, Gateshead.
1863. Hall, Joseph, Gratz Iron Works, Gratz, Styria, Austria.
1857. Hall, William, 167 Dartmouth Street, Birmingham.
1860. Hamilton, Gilbert, Messrs. James Watt and Co., Soho Foundry, near Birmingham.
1858. Harding, John, Beeston Manor Iron Works, Leeds.
1859. Harman, Henry William, Canal Street Works, Manchester.
1856. Harrison, George, Canada Works, Birkenhead.
1858. Harrison, Thomas Elliot, 1 Westminster Chambers, Victoria Street, Westminster, S.W.
1865. Harrison, William, Bank Foundry, Blackburn.
1865. Harrison, William Arthur, Cambridge Street Works, Manchester.
1858. Haswell, John A., North Eastern Railway, Locomotive Department, Gateshead.
1857. Haughton, S. Wilfred, Greenbank, Carlow. (*Life Member.*)
1861. Hawkins, William Bailey, 2 Suffolk Lane, Cannon Street, London, E.C.
1856. Hawksley, Thomas, 30 Great George Street, Westminster, S.W.
1848. Hawthorn, Robert, Forth Banks, Newcastle-on-Tyne.
1848. Hawthorn, William, Forth Banks, Newcastle-on-Tyne.
1862. Haynes, Thomas John, Calpe Foundry, North Front, Gibraltar.
1860. Head, John, Messrs. Ransomes and Sims, Orwell Works, Ipswich.
1853. Headly, James Ind, Eagle Foundry, Cambridge.
1857. Healey, Edward Charles, 163 Strand, London, W.C.

1862. Heath, William J. W., 14 Strand, London, W.C.
1864. Heathfield, Richard, Lion Galvanising Works, Birmingham Heath, Birmingham.
1860. Heaton, George, Royal Copper Mint, Icknield Street East, Birmingham.
1865. Hetherington, John Muir, Vulcan Works, Pollard Street, Manchester.
1866. Hetherington, Thomas Ridley, Vulcan Works, Pollard Street, Manchester.
1864. Hetherington, William Isaac, Vulcan Works, Pollard Street, Manchester.
1865. Hewett, Edward Edwards, Yorkshire Engine Co., Meadow Hall Works, near Sheffield.
1866. Hickman, George Haden, Groveland Iron Works, Dudley Port, Tipton.
1864. Hide, Thomas C., 46 Fenchurch Street, London, E.C.
1863. Hind, Roger, Scotland Bank Iron Works, Warrington.
1866. Hodgson, Charles, 163 Strand, London, W.C.
1858. Hodgson, Robert, North Eastern Railway, Newcastle-on-Tyne.
1852. Holcroft, James, Shut End, Brierley Hill.
1866. Holcroft, Thomas, Bilston Foundry, Bilston.
1865. Holliday, John, Messrs. Bethell's Creosote Works, Westbromwich.
1863. Holt, Francis, Gorton Foundry, Manchester.
1867. Holt, William Lyster, 6 Storey's Gate, Westminster, S.W.
1867. Homer, Charles James, Mining Engineer, Chatterley Ironstone Works, Tunstall, near Stoke-upon-Trent.
1848. Homersham, Samuel Collett, 19 Buckingham Street, Adelphi, London, W.C.
1860. Hopkins, James Innes, Tees Side Iron Works, Middlesbrough.
1866. Hopkins, John Satchell, Tinplate Works, Granville Street, Birmingham.
1856. Hopkinson, John, London Road Iron Works, Manchester.
1858. Hopper, George, Houghton-le-Spring Iron Works, near Fence Houses.
1867. Hopper, William, Machine Works, Moscow, Russia.
1867. Horrocks, Samuel, 51 King Street, Manchester.
1858. Horsley, William, Jun., Whitehill Point Iron Works, Percy Main, near Newcastle-on-Tyne.
1851. Horton, Joshua, Ætna Works, Smethwick, near Birmingham.
1867. Horton, Thomas Ellwood, Lilleshall Iron Works, Oakengates, near Wellington, Shropshire.
1858. Hosking, John, Gateshead Iron Works, Gateshead.
1866. Houghton, John Campbell Arthur, Woodside Iron Works, near Dudley.
1864. Howard, Eliot, 84 Upper Whitecross Street, London, E.C.
1860. Howard, James, Britannia Iron Works, Bedford.
1867. Howard, Robert Luke, 84 Upper Whitecross Street, London, E.C.
1860. Howe, William, Clay Cross Coal and Iron Works, near Chesterfield.
1861. Howell, Joseph Bennett, Hartford Steel Works, Sheffield.
1866. Hoyle, William Jennings, Messrs. Whitworth and Co., Chorlton Street, Manchester.
1867. Hughes, George Douglas, Queen's Foundry, London Road, Nottingham.

1864. Hulse, William Wilson, Whalley Chambers, 88 King Street, Manchester.
1847. Humphrys, Edward, Deptford Pier, London, S.E.
1859. Hunt, James P., Gospel Oak Iron Works, Tipton.
1856. Hunt, Thomas, 19 Godolphin Road, New Road, Hammersmith, London, W.
1864. Hutchinson, Edward, Skerne Iron Works, Darlington.
1863. Hutton, Walter Stuart, Prospect Works, Hunslet Lane, Leeds.
1865. Hyde, Lt.-Colonel Henry, R.E., Master of the Mint, Calcutta: (or care of Rev. H. M. C. Hyde, 14 Grove Lane, Camberwell, London, S.E.) (*Life Member.*)

1867. Inglis, William, Manchester Chambers, 97 Bridge Street, Manchester.
1866. Ireland, William, 41 Beech Lane, Macclesfield.

1865. Jackson, John, Stibbington House, Wansford.
1859. Jackson, Matthew Murray, Engineer-in-Chief, Imperial Danube Steam Navigation Works, Pesth, Austria.
1847. Jackson, Peter Rothwell, Salford Rolling Mills, Manchester.
1861. Jackson, Robert, Ætna Steel Works, Sheffield.
1860. Jackson, Samuel, Cyclops Steel and Iron Works, Sheffield.
1866. Jaeger, Herrmann Frederic, Gorton Foundry, Manchester.
1858. Jaffrey, George William, Hartlepool Iron Works, Hartlepool.
1856. James, Jabez, 40 Prince's Street, Commercial Road, Lambeth, London, S.E.
1861. Jeffcock, Thomas William, Mining Engineer, 18 Bank Street, Sheffield.
1863. Jeffreys, Edward A., Low Moor Iron Works, near Bradford, Yorkshire.
1857. Jenkins, William, Locomotive Superintendent, Lancashire and Yorkshire Railway, Miles Platting, Manchester.
1861. Jessop, Thomas, Park Steel Works, Sheffield.
1854. Jobson, John, Derwent Foundry, Derby.
1863. Johnson, Bryan, Flookersbrook Foundry, Chester.
1847. Johnson, James, North Staffordshire Railway, Engineer's Office, Stoke-upon-Trent.
1861. Johnson, Samuel Waite, Locomotive Superintendent, Great Eastern Railway, Stratford, London, E.
1861. Jones, David, Ty Du, Rogerstone, Newport, Monmouthshire.
1847. Jones, Edward, The Larches, Handsworth, near Birmingham.
1857. Jones, Hodgson, 67 Victoria Street, Westminster, S.W.
1853. Joy, David, Cleveland Engine Works, Middlesbrough.

1857. Kay, James Clarkson, Phœnix Foundry, Bury, Lancashire.
1867. Kellett, John, 2 Newshams Buildings, King Street, Wigan.
1857. Kendall, William, Locomotive Superintendent, Blyth and Tyne Railway, Percy Main, near Newcastle-on-Tyne.

1863. Kennan, James, Agricultural Implement Works, 19 Fishamble Street, Dublin.

1847. Kennedy, James, Cressington Park, Aigburth, Liverpool.

1857. Kennedy, Lt.-Colonel John Pitt, Engineer, Bombay Baroda and Central Indian Railway; 45 Finsbury Circus, London, E.C.

1863. Kennedy, John Pitt, Bombay Baroda and Central Indian Railway; 45 Finsbury Circus, London, E.C.

1866. Kershaw, John, 24 Duke Street, Westminster, S.W.

1867. Kimball, Frederick James, 35 South Third Street, Philadelphia, Pennsylvania, United States.

1865. Kirkaldy, David, Testing and Experimental Works, The Grove, Southwark Street, London, S.E.

1847. Kirtley, Matthew, Locomotive Superintendent, Midland Railway, Derby.

1864. Kirtley, William, Midland Railway, Locomotive Department, Derby.

1859. Kitson, Frederick William, Monkbridge Iron Works, Leeds.

1848. Kitson, James, Airedale Foundry, Leeds.

1859. Kitson, James, Jun., Monkbridge Iron Works, Leeds.

1866. Knap, Conrad, 5 Bridge Street, Westminster, S.W.

1863. Knight, Thomas, 130 Bradford Street, Birmingham.

1866. Lambert, William Blake, Berwick-upon-Tweed.

1867. Lancaster, Charles William, Gun Manufactory, 151 New Bond Street, London, W.

1863. Lancaster, John, Kirkless Hall Coal and Iron Works, near Wigan.

1863. Latham, Ernest, 4 Clifton Terrace, Southsea, near Portsmouth.

1860. Law, David, Phœnix Iron Works, Glasgow.

1867. Lawrence, Henry, The Grange Iron Works, Durham.

1857. Laybourn, John, Isca Foundry, Newport, Monmouthshire.

1856. Laybourn, Richard, Locomotive Superintendent, Monmouthshire Railway and Canal Company, Newport, Monmouthshire.

1860. Lea, Henry, 35 Paradise Street, Birmingham.

1865. Ledger, Joseph, West Cumberland Hæmatite Iron Works, Workington.

1862. Lee, J. C. Frank, 22 Great George Street, Westminster, S.W.

1863. Lees, Samuel, Jun., Park Bridge Iron Works, Ashton-under-Lyne.

1863. Leigh, Evan, Junction Works, Miles Platting, Manchester.

1865. Leigh, Frederick Allen, Junction Works, Miles Platting, Manchester.

1866. Leigh, Joseph, Ellesmere Foundry, Patricroft, near Manchester.

1858. Leslie, Andrew, Iron Ship Building Yard, Hebburn Quay, Gateshead.

1856. Levick, Frederick, Cwm-Celyn Blaina and Coalbrook Vale Iron Works, near Newport, Monmouthshire.

1860. Lewis, Thomas William, Abercanaid House, Merthyr Tydvil.

1864. Lindsley, George, Great Western Railway, Locomotive Department, Swindon.

1856. Linn, Alexander Grainger, 2 Queen Square Place, Westminster, S.W.
1857. Little, Charles, Staveley Coal and Iron Works, Staveley, near Chesterfield.
1866. Little, George, Hartford Iron Works, Oldham.
1867. Livesey, James, 9 Victoria Chambers, Victoria Street, Westminster, S.W.
1867. Lloyd, Charles, 6 Westminster Chambers, Victoria Street, Westminster, S.W.
1863. Lloyd, Edward R., Albion Tube Works, Nile Street, Birmingham.
1854. Lloyd, George Braithwaite, Messrs. Lloyds, High Street, Birmingham. (*Life Member.*)
1862. Lloyd, John, Lilleshall Iron Works, Oakengates, near Wellington, Shropshire.
1866. Lloyd, Joseph Foster, Darlaston Green Iron and Steel Works, near Wednesbury.
1847. Lloyd, Sampson, Old Park Iron Works, Wednesbury.
1864. Lloyd, Sampson Zachary, Old Park Iron Works, Wednesbury.
1852. Lloyd, Samuel, Old Park Iron Works, Wednesbury.
1862. Lloyd, Wilson, Moor Hall, Sutton Coldfield, near Birmingham.
1863. Loam, Matthew Hill, Engineer, Gas and Water Works, Nottingham.
1856. Longridge, Robert Bewick, Steam Boiler Assurance Company, 67 King Street, Manchester.
1865. Longridge, William Smith, Alderwasley Iron Works, Ambergate, near Derby.
1866. Lord, Edward, Canal Street Works, Todmorden.
1859. Lord, Thomas Wilks, Bank Mills, Leeds.
1861. Low, George, St. Peter's Iron Works, Ipswich.
1865. Lundh, Sverier Hakon, 8 Lille Strandgade, Christiania, Norway: (or 9B New Broad Street, London, E.C.)
1854. Lynde, James Gascoigne, Town Hall, Manchester.

1864. Macfarlane, Walter, Saracen Foundry, Glasgow.
1856. Mackay, John, Mount Hermon, Drogheda.
1864. Macnab, Archibald Francis, Peninsular and Oriental Steam Navigation Co., Hong Kong, China: (or care of P. and O. S. N. Co., 122 Leadenhall Street, London, E.C.)
1865. MacNay, William, Shildon Engine Works, Darlington.
1865. Macnee, Daniel, Cyclops Steel and Iron Works, Sheffield.
1867. Mallet, Robert, 7 Westminster Chambers, Victoria Street, Westminster, S.W.
1859. Manning, John, Boyne Engine Works, Hunslet, Leeds.
1862. Mansell, Richard Christopher, South Eastern Railway, Carriage Department, Ashford.
1862. Mappin, Frederick Thorpe, Sheaf Works, Sheffield.
1857. March, George, Union Foundry, Leeds.
1856. Markham, Charles, Staveley Coal and Iron Works, Staveley, near Chesterfield.

1865. Marshall, Francis Carr, Jarrow Engine Works, Quayside, Newcastle-on-Tyne.

1862. Marshall, James, George's Road, Scotswood Road, Newcastle-on-Tyne.

1859. Marshall, William Ebenezer, Sun Foundry, Leeds.

1847. Marshall, William Prime, 81 Newhall Street, Birmingham.

1859. Marten, Edward Bindon, Engineer, Stourbridge Water Works, 13 High Street, Stourbridge.

1853. Marten, Henry, Parkfield Iron Works, near Wolverhampton.

1867. Martin, William, Messrs. W. Martin Fils et Cie., 43 Rue d'Elbeuf, Rouen, France.

1857. Martindale, Captain Ben Hay, R.E., War Office, Pall Mall, London, S.W.

1854. Martineau, Francis Edgar, Globe Works, Cliveland Street, Birmingham.

1864. Martley, William, Locomotive Superintendent, London Chatham and Dover Railway, Longhedge Works, Wandsworth Road, London, S.W.

1857. Masselin, Armand, Glass Works, Folembray, Aisne, France.

1867. Mather, William, Salford Iron Works, Manchester.

1853. Mathews, William, North Grove, Great Malvern.

1848. Matthew, John, 13 Park Street, Park Lane, London, W.

1847. Matthews, William Anthony, Sheaf Works, Sheffield.

1853. Maudslay, Henry, Bystock, near Exmouth. (*Life Member.*)

1864. Maudslay, Thomas Henry, 110 Westminster Bridge Road, Lambeth, London, S.E.

1861. May, Robert Charles, 6 Great George Street, Westminster, S.W.

1857. May, Walter, Suffolk Works, Berkley Street, Birmingham.

1865. Maylor, John, Engineer and Shipbuilder, Rio de Janeiro, Brazil; 11 Commerce Chambers, Lord Street, Liverpool.

1859. Maylor, William, Calicut, Madras, India.

1847. McClean, John Robinson, 23 Great George Street, Westminster, S.W.

1865. McDonnell, Alexander, Locomotive Superintendent, Great Southern and Western Railway, Dublin.

1867. McEwen, James, Wordsley Foundry, Stourbridge.

1864. McEwen, Lawrence Thompson, Ormesby Iron Works, Middlesbrough.

1860. McKenzie, James, Well House Foundry, Leeds.

1859. McKenzie, John, Worcester Engine Works, Worcester.

1863. Meek, Sturges, Resident Engineer, Lancashire and Yorkshire Railway, Manchester.

1858. Meik, Thomas, Engineer to the River Wear Commissioners, Sunderland.

1857. Menelaus, William, Dowlais Iron Works, Merthyr Tydvil.

1866. Meredith, Alban, 107 Lionel Street, Birmingham.

1867. Merryweather, Richard M., 63 Long Acre, London, W.C.

1857. Metford, William Ellis, Flook House, Taunton.

1847. Middleton, William, Vulcan Iron Foundry, Summer Lane, Birmingham.

1862. Miers, Francis C., Stoneleigh Lodge, Grove Road, Clapham Park, London, S.W.
1864. Miers, John William, 74 Addison Road, Kensington, London, W.
1862. Millward, John, 27 Paradise Street, Birmingham.
1856. Mitchell, Charles, The Grange, Surbiton Hill, Kingston-on-Thames.
1858. Mitchell, James, 5 Church Terrace, Higher Tranmere, Birkenhead.
1861. Mitchell, Joseph, Worsbrough Dale Colliery, near Barnsley.
1859. Moor, William, Engineer, Hetton Colliery, Hetton, near Fence Houses.
1864. Moore, Sampson, North Foundry, Cotton Street, Clarence Dock, Liverpool.
1864. Morgan, Joshua Llewelyn, Kingscombe, near Cowbridge.
1867. Morgans, Thomas, Foundry and Wagon Works, Pontypool.
1849. Morrison, Robert, Ouseburn Engine Works, Newcastle-on-Tyne.
1865. Morton, Robert, Alliance Chambers, Borough, London, S.E.
1865. Mosse, James Robert, Mauritius Railways, Port Louis, Mauritius.
1858. Mountain, Charles George, Suffolk Works, Berkley Street, Birmingham.
1866. Muir, Andrew, Britannia Works, Sherborne Street, Strangeways, Manchester.
1863. Muir, William, 57 Claverton Street, Pimlico, London, S.W.
1865. Murdock, William Mallabey, Barrow Hæmatite Steel Works, Barrow-in-Furness, Lancashire.
1859. Murphy, James, Railway Works, Newport, Monmouthshire.
1858. Murray, Thomas H., Engine Works, Chester-le-Street, near Fence Houses.
1863. Musgrave, John, Jun., Globe Iron Works, Bolton.

1848. Napier, John, Vulcan Foundry, Glasgow.
1867. Napier, John D., Kilmun House, Holt Hill, Birkenhead.
1856. Napier, Robert, West Shandon, Helensburgh, near Glasgow. (*Life Member.*)
1861. Naylor, John William, Wellington Foundry, Leeds.
1858. Naylor, William, Great Indian Peninsula Railway, 3 New Broad Street, London, E.C.
1863. Neilson, Walter Montgomerie, Hyde Park Locomotive Works, Glasgow.
1860. Nettlefold, Joseph Henry, Screw Works, Broad Street, Birmingham.
1866. Newdigate, Albert Lewis, Byrkley Lodge, near Burton-on-Trent.
1862. Newton, William Edward, 66 Chancery Lane, London, W.C.
1858. Nichol, Peter Dale, care of Anthony Nichol, 19 Quay, Newcastle-on-Tyne.
1866. Norfolk, Richard, Beverley Iron and Wagon Works, Beverley.
1850. Norris, Richard Stuart, 272 Upper Parliament Street, Liverpool.

1866. Oliver, William, Victoria Foundry, Chesterfield.
1867. Olrick, Lewis, 27 Leadenhall Street, London, E.C.
1864. Ommanney, Frederick Francis, New Bridge Foundry, Adelphi Street, Salford, Manchester.

1867. Oughterson, George Blake, Messrs. W. Martin Fils et Cie., 43 Rue d'Elbeuf, Rouen, France.
1847. Owen, William, Phœnix Wheel Tyre and Axle Works, Rotherham.

1865. Parkes, Alexander, Stephenson Metal Tube Works, Liverpool Street, Birmingham.
1860. Parkin, John, Harvest Lane Steel Works, Sheffield.
1866. Parton, Thomas, Rough Hay Iron Works, Darlaston, near Wednesbury.
1847. Peacock, Richard, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.
1867. Pearce, Robert Webb, Carriage Superintendent, East Indian Railway, Calcutta, India.
1848. Pearson, John, 7 Old Hall Street, Liverpool.
1866. Peel, George, Jun., Soho Iron Works, Pollard Street, Manchester.
1866. Peele, Arthur John, New Cross Works, Deptford, London, S.E.
1848. Penn, John, The Cedars, Lee, Kent, S.E. (*Life Member.*)
1861. Perkins, Loftus, 6 Seaford Street, Regent Square, London, W.C.
1866. Perks, John Hartley, Shrubbery Iron Works, Wolverhampton.
1856. Perring, John Shae, 104 King Street, Manchester.
1863. Perry, Thomas J., Highfields Engine Works, Bilston.
1865. Perry, William, Messrs. Samuel Perry and Sons, Wednesbury.
1860. Peyton, Edward, Bordesley Works, Birmingham.
1867. Pidgeon, Daniel, Britannia Iron Works, Banbury.
1856. Piggott, George, Birmingham Heath Boiler Works, Birmingham.
1854. Pilkington, Richard, Jun., Wolsingham, near Darlington.
1859. Pitts, Joseph, Stanningley Iron Works, near Leeds.
1859. Platt, John, M.P., Hartford Iron Works, Oldham.
1867. Platt, Samuel Radcliffe, Hartford Iron Works, Oldham.
1862. Player, John, Aislaby Hall, Whitby, Yorkshire.
1866. Plum, Thomas Edward Day, Atlas Works, Manchester.
1861. Plum, Thomas William, Old Park Iron Works, near Shiffnal.
1856. Pollard, John, Midland Junction Foundry, Leeds.
1860. Ponsonby, Edward Vincent, Parker Place, Broomhill, Sheffield.
1866. Porter, Charles Talbot, 102 Broadway, New York, United States.
1852. Porter, John Henderson, 7 St. Mildred's Court, Poultry, London, E.C.
1861. Porter, Robert, Ebro Works, Tividale, near Tipton.
1864. Potts, Benjamin Langford Foster, 200 Camberwell Grove, London, S.E.
1851. Potts, John Thorpe, 200 Camberwell Grove, London, S.E.
1867. Powell, William, Harbour Works, Port Erin, Isle of Man.
1867. Pratchitt, John, Denton Iron Works, Carlisle.
1865. Pratchitt, William, Denton Iron Works, Carlisle.
1856. Preston, Francis, Ancoats Bridge Works, Ardwick, Manchester.

1866. Price, John, Chief Surveyor, Underwriters' Registry for Iron Vessels, 42 Villiers Street, Sunderland.

1866. Putnam, William, Darlington Forge, Darlington.

1862. Rake, Alfred Stansfield, Bank Buildings, Newcastle-on-Tyne.

1864. Ramage, Robert, Locomotive Superintendent, Midland Great Western Railway, Dublin.

1847. Ramsbottom, John, Locomotive Superintendent, London and North Western Railway, Crewe.

1866. Ramsden, James, Abbot's Wood, Barrow-in-Furness, Lancashire.

1860. Ransome, Allen, Jun., Messrs. Worssam and Co., King's Road, Chelsea, London, S.W.

1862. Ransome, Robert James, Orwell Works, Ipswich.

1867. Ratcliff, Daniel Rowlinson, Phœnix Safe Works, Liverpool.

1867. Ratliffe, George, London and North Western Railway, Locomotive Department, Crewe.

1862. Ravenhill, John R., Glass House Fields, Ratcliff, London, E.

1859. Rennie, George Banks, 20 Lowndes Street, Lowndes Square, London, S.W.

1862. Reynolds, Edward, Don Steel Works, Sheffield.

1866. Reynolds, Frederic Cornell, 37 Great George Street, Westminster, S.W.

1866. Richards, Edward Windsor, Ebbw Vale Iron Works, near Tredegar.

1863. Richards, Edwin, Tredegar Iron Works, Tredegar.

1865. Richards, Job, Crockett Road, Handsworth, near Birmingham.

1856. Richards, Josiah, Abersychan Iron Works, Pontypool.

1863. Richardson, Edward, Lyttelton and Christchurch Railway, Christchurch, New Zealand.

1865. Richardson, John, Borough Engineer, Town Hall, Halifax.

1858. Richardson, Thomas, Hartlepool Iron Works, Hartlepool.

1859. Richardson, William, Hartford Iron Works, Oldham.

1865. Rideal, Samuel, 18 Hopwood Avenue, Manchester.

1863. Rigby, Samuel, Cock Hedge Mill, Warrington.

1848. Robertson, Henry, Great Western Railway, Shrewsbury.

1865. Robey, Robert, Perseverance Iron Works, Lincoln.

1859. Robinson, John, Messrs. Sharp Stewart and Co., Atlas Works, Manchester.

1865. Robinson, John, Railway Works, Rochdale.

1866. Robson, Thomas, Mining Engineer, Lumley Colliery, Fence Houses.

1853. Ronayne, Joseph P., 4 Harbour Hill, Queenstown.

1867. Rose, Henry Fullwood, Albert Iron Works, Moxley, near Wednesbury.

1866. Rose, Thomas, Bradley Iron Works, near Bilston.

1867. Rose, Thomas, Machine Works, 37 Victoria Street, Manchester.

1866. Rosthorn, Joseph De, 25 Turkenstrasse, Alsergrund, Vienna.

1856. Rouse, Frederick, Great Northern Railway, Locomotive Department, Boston.

1857. Routledge, William, New Bridge Foundry, Adelphi Street, Salford, Manchester.

1860. Rumble, Thomas William, 5 Westminster Chambers, Victoria Street, Westminster, S.W. (*Life Member.*)

1847. Russell, John Scott, 5 Westminster Chambers, Victoria Street, Westminster, S.W.

1867. Ruston, Joseph, Sheaf Iron Works, Lincoln.

1863. Ryder, William, Bark Street, Bolton.

1866. Sacré, Alfred, Yorkshire Engine Co., Meadow Hall Works, near Sheffield.

1859. Sacré, Charles, Locomotive Superintendent, Manchester Sheffield and Lincolnshire Railway, Gorton, near Manchester.

1867. Sadoine, Eugène, Société Cockerill, Seraing, Belgium.

1864. Said, Colonel M., Bey, Engineer, Turkish Service, Constantinople: (or care of J. C. Frank Lee, 22 Great George Street, Westminster, S.W.)

1859. Salt, George, Saltaire, near Bradford, Yorkshire.

1864. Samuda, Joseph D'Aguilar, M.P., Iron Ship Building Yard, Isle of Dogs, Poplar, London, E.

1848. Samuel, James, 26 Great George Street, Westminster, S.W.

1857. Samuelson, Alexander, 27 Cornhill, London, E.C.

1865. Samuelson, Bernhard, M.P., Britannia Iron Works, Banbury.

1857. Samuelson, Martin, Engine Works, Neptune Street, Hull.

1865. Sandberg, Christer Peter, Engineer, Swedish Government Railway Service, Stockholm, Sweden: (or care of Messrs. Tottie and Sons, 2 Alderman's Walk, Bishopsgate Street, London, E.C.)

1861. Sanderson, George Grant, Tudhoe Iron Works, near Ferryhill.

1864. Sanderson, John, Flosh View, Wigton.

1860. Schneider, Henry William, Ulverstone Hæmatite Iron Works, Barrow-in-Furness, Lancashire.

1866. Scholtze, Aleksander, Messrs. Scholtze Brothers, Engineers and Boiler Makers, Warsaw, Poland.

1865. Scott, Edward, 10 Tib Lane, Cross Street, Manchester.

1861. Scott, Walter Henry, Locomotive and Carriage Superintendent, Mauritius Railways, Port Louis, Mauritius: (or care of Joseph Reid, 3 Alexander Terrace, Stanstead Road, Forest Hill, London, S.E.)

1864. Seddon, John, Wallgate, Wigan.

1857. Selby, George Thomas, Smethwick Tube Works, Birmingham.

1867. Selby, Millin, Teakova Cotton Mill, near Ivanova, Vladimir, Russia: (or care of Millin Selby, Sen., Atherton Hall, Leigh, near Manchester.)

1865. Sellers, William, Pennsylvania Avenue, Philadelphia, United States.

1850. Shanks, Andrew, 6 Robert Street, Adelphi, London, W.C.

1863. Sharp, Henry, Bolton Iron and Steel Works, Bolton.

1867. Sharpe, Charles James, 1 Victoria Street, Westminster, S.W.

1862. Sharpe, William John, 1 Victoria Street, Westminster, S.W.

1864. Shaw, Duncan, Mining Engineer, Cordova, Spain.

1866. Shaw, Frank, Burton Iron Works, Burton-on-Trent.

1856. Shelley, Charles Percy Bysshe, 21 Parliament Street, Westminster, S.W.

1861. Shepherd, John, Union Foundry, Hunslet Road, Leeds.

1859. Shuttleworth, Joseph, Stamp End Iron Works, Lincoln.

1851. Siemens, Charles William, 3 Great George Street, Westminster, S.W.

1862. Silvester, John, Messrs. George Salter and Co., Spring Balance Works, Westbromwich.

1847. Sinclair, Robert, Great Eastern Railway, Stratford, London, E.

1857. Sinclair, Robert Cooper, Hartshill, near Atherstone.

1859. Slater, Isaac, Gloucester Wagon Works, Gloucester.

1853. Slaughter, Edward, Avonside Engine Works, Bristol.

1866. Smethurst, Joseph, Guide Bridge Iron Works, Audenshaw, near Manchester.

1866. Smith, Edward Fisher, Coneygre Iron Works, Dudley Port, Dudley.

1866. Smith, Fereday, Bridgewater Offices, Manchester.

1860. Smith, Henry, Brierley Hill Iron Works, Brierley Hill.

1858. Smith, Isaac, 36 Lancaster Street, Birmingham.

1860. Smith, John, Brass Foundry, Traffic Street, Derby.

1857. Smith, Josiah Timmis, Ulverstone Hæmatite Iron Works, Barrow-in-Furness, Lancashire.

1859. Smith, Matthew, Caledonia Wire Mills, Halifax.

1857. Smith, William, 19 Salisbury Street, Adelphi, London, W.C.

1866. Smith, William, Eglinton Engine Works, Glasgow.

1863. Smith, William Ford, Gresley Iron Works, Ordsal Lane, Salford, Manchester.

1857. Snowdon, Thomas, 147 High Street, Stockton-on-Tees.

1859. Sokoloff, Captain Alexander, Engineer, Russian Imperial Service, Steam Marine Department, Cronstadt, Russia: (or care of Messrs. W. Collier and Co., 2 Greengate, Salford, Manchester.)

1863. Somerville, Wallace Cochrane, London Works, Birmingham.

1858. Sörensen, Bergerius, Engineer-in-Chief, Royal Norwegian Navy Department, Horten Dockyard, Norway: (or care of Messrs. Tottie and Sons, 2 Alderman's Walk, Bishopsgate Street, London, E.C.)

1865. Sparrow, Arthur, Lane End Iron Works, Longton, near Stoke-upon-Trent.

1865. Sparrow, William Mander, Osier Bed Iron Works, Wolverhampton.

1866. Spencer, Eli, Hartford Iron Works, Oldham.

1859. Spencer, John Frederick, Sunderland Engine Works, South Dock, Sunderland.

1867. Spencer, John W., Newburn Steel Works, Newcastle-on-Tyne.

1853. Spencer, Thomas, Clough Hall Iron Works, Kidsgrove, near Stoke-upon-Trent.

1854. Spencer, Thomas, Newburn Steel Works, Newcastle-on-Tyne.

1864. Spittle, Thomas, Cambrian Iron Foundry, Newport, Monmouthshire.

1862. Stableford, William, Oldbury Carriage Works, near Birmingham.

1866. Stephens, John Classon, Blackhall Place Iron Works, Dublin.

1866. Stevenson, John, Acklam Iron Works, Middlesbrough.

1867. Stevenson, Robert, Mining Engineer, Clay Cross, near Chesterfield.

1859. Stewart, Charles P., Messrs. Sharp Stewart and Co., Atlas Works, Manchester.

1851. Stewart, John, Blackwall Iron Works, Russell Street, Blackwall, London, E.

1867. Stirling, Patrick, Locomotive Superintendent, Great Northern Railway, Doncaster.

1864. Stokes, James Folliott, 21 Parliament Street, Westminster, S.W.

1863. Storey, John Henry, Knott Mill Brass and Copper Works, Little Peter Street, Manchester.

1862. Strong, Joseph F., Resident Engineer, East Indian Railway, Cawnpore, India.

1865. Stroudley, William, Locomotive Superintendent, Highland Railway, Inverness.

1861. Sumner, William, 21 Clarence Street, Manchester.

1860. Swindell, James Evers, Parkhead Iron Works, Dudley.

1864. Swindell, James Swindell Evers, Cradley Iron Works, near Brierley Hill.

1867. Swingler, Henry, Victoria Foundry, Litchurch, near Derby.

1859. Swingler, Thomas, Victoria Foundry, Litchurch, near Derby.

1861. Tangye, James, Cornwall Works, Clement Street, Birmingham.

1859. Tannett, Thomas, Victoria Foundry, Leeds.

1861. Taylor, George, Clarence Iron Works, Leeds.

1858. Taylor, James, Britannia Engine Works, Cleveland Street, Birkenhead.

1862. Taylor, John, Mining Engineer, 6 Queen Street Place, Upper Thames Street, London, E.C.

1867. Taylor, Joseph, Iron Foundry, Constitution Hill, Birmingham.

1862. Taylor, Richard, Mining Engineer, 6 Queen Street Place, Upper Thames Street, London, E.C.

1864. Tennant, Charles, The Glen, Innerleithen, near Edinburgh. (*Life Member.*)

1867. Thomas, Joseph Lee, Engineer, Foxdale Lead Mines, Douglas, Isle of Man.

1864. Thomas, Thomas, Llynvi Vale Iron Works, near Bridgend.

1857. Thompson, Robert, Haigh Foundry, near Wigan.

1862. Thompson, William, Spring Gardens Engine Works, Newcastle-on-Tyne.

1852. Thomson, George, Crookhay Iron Works, Westbromwich.

1865. Thorn, Alexander, Steam Saw Mills, Chelsea, London, S.W.

1861. Thwaites, Robinson, Vulcan Iron Works, Thornton Road, Bradford, Yorkshire.

1865. Tickle, John, Providence Engine Works, Westbromwich.

1862. Tijou, William, 27 Great George Street, Westminster, S.W.
1862. Tolmé, Julian Horn, 1 Victoria Street, Westminster, S.W.
1857. Tomlinson, Joseph, Jun., Locomotive Superintendent, Taff Vale Railway, Cardiff.
1867. Tonks, Edmund, Brass Works, Moseley Street, Birmingham.
1865. Toomey, Edward, Royal Phœnix Iron Works, Dublin.
1856. Tosh, George, Locomotive Superintendent, Maryport and Carlisle Railway, Maryport.
1860. Townsend, Thomas C., 16 Talbot Chambers, Shrewsbury.
1863. Townsend, William, West Orchard, Coventry.
1865. Trow, John James, Timber Works, Bilston Road, Wednesbury.
1862. Troward, Charles, 8 Sussex Terrace, Camden Town, London, N.W.
1859. Turner, Edwin, Bowling Iron Works, near Bradford, Yorkshire.
1866. Turner, Frederick, St. Peter's Iron Works, Ipswich.
1867. Turner, Henry, Thames Ship Building Works, Orchard Yard, Blackwall, London, E.
1867. Tweddell, Ralph Hart, 44 West Sunniside, Sunderland.
1856. Tyler, Captain Henry Wheetley, R.E., Railway Department, Board of Trade, Whitehall, London, S.W.

1862. Upward, Alfred, Engineer, Chartered Gas Works, 146 Goswell Street, London, E.C.
1865. Usher, George Moon, Beverley Iron Works, Beverley.

1862. Vavasseur, Josiah, 28 Gravel Lane, Southwark, London, S.E.
1856. Vernon, John, Regent Road, Sandon Dock, Liverpool.
1865. Vickers, Albert, Don Steel Works, Sheffield.
1861. Vickers, Thomas Edward, Don Steel Works, Sheffield.

1856. Waddington, John, 35 King William Street, London Bridge, London, E.C.
1856. Waddington, Thomas, Heaton Lodge, Wortley, near Leeds.
1865. Wainwright, William, Great Western Railway, Locomotive Department, Worcester.
1863. Wakefield, John, Locomotive Superintendent, Dublin Wicklow and Wexford Railway, Dublin.
1867. Walker, Benjamin, Goodman Street Works, Hunslet, Leeds.
1864. Walker, Bernard Peard, Junction Cut Nail Works, Wolverhampton.
1867. Walker, Charles Clement, Midland Iron Works, Donnington, near Newport, Shropshire.
1861. Walker, John G., Netherton Iron Works, near Dudley.
1847. Walker, Thomas, Patent Shaft Works, Wednesbury.
1863. Walker, William Hugill, Wicker Iron Works, Sheffield.

1863. Wallace, William, Superintending Engineer, Montreal Ocean Steam Ship Works, Liverpool.

1865. Waller, George Arthur, Messrs. Guinness, James' Gate, Dublin.

1865. Walpole, Thomas, Port of Dublin Ship Yard, Dublin.

1864. Warden, Walter Evers, Phœnix Bolt and Nut Works, Glover Street, Birmingham.

1856. Wardle, Charles Wetherell, Boyne Engine Works, Hunslet, Leeds.

1852. Warham, John R., Burton Iron Works, Burton-on-Trent.

1867. Watkin, William John Laverick, Mining Engineer, Pemberton Colliery, near Wigan.

1862. Watkins, Richard, Canal Iron Works, Poplar, London, E.

1866. Watson, Robert, Engineer, Black Boy Collieries, Bishop Auckland.

1862. Webb, Francis William, Bolton Iron and Steel Works, Bolton.

1862. Webb, Henry Arthur, Bretwell Hall Iron Works, near Stourbridge.

1860. Weild, William, Tipping Street, Ardwick, Manchester.

1862. Wells, Charles, Moxley Iron Works, near Bilston.

1862. Westmacott, Percy G. B., Elswick Engine Works, Newcastle-on-Tyne.

1867. Weston, Thomas Aldridge, care of Messrs. B. H. Harris and Co., 78 Parade, Birmingham.

1867. Wheatley, Thomas, Locomotive Superintendent, North British Railway, Edinburgh.

1856. Wheeldon, Frederick R., Highfields Engine Works, Bilston.

1864. White, Isaiah, Messrs. Portilla and White, Engineers and Iron Ship Builders, Seville, Spain: (or care of Isaac White, Pontardulais, Llanelly.)

1859. Whitham, James, Perseverance Iron Works, Kirkstall Road, Leeds.

1863. Whitley, Joseph, New British Iron Works, Corngreaves, near Birmingham.

1866. Whitwell, Thomas, Thornaby Iron Works, Stockton-on-Tees.

1847. Whitworth, Joseph, Chorlton Street, Manchester.

1859. Wickham, Henry Wickham, M.P., Low Moor Iron Works, near Bradford, Yorkshire.

1859. Wickham, Lamplugh Wickham, Low Moor Iron Works, near Bradford, Yorkshire.

1863. Wicksteed, Thomas, 8 Torquay Terrace, Headingley, near Leeds. (*Life Member.*)

1867. Wilkes, Gilbert, Tube Works, Bordesley Mills, Birmingham.

1867. Wilkes, John, Tube Works, Bordesley Mills, Birmingham.

1865. Williams, Edward, Messrs. Bolckow and Vaughan's Iron Works, Middlesbrough.

1847. Williams, Richard, Patent Shaft Works, Wednesbury.

1859. Williams, Richard Price, London Iron and Steel Works, East Greenwich, S.E.

1856. Wilson, Edward, Great Western Railway, Worcester.

1859. Wilson, George, Cyclops Steel and Iron Works, Sheffield.

1867. Wilson, Henry, Brass Works, Stockton-on-Tees.
1865. Wilson, James Edwards, Engineer, Indian Branch Railways, Cawnpore, India.
1863. Wilson, John Charles, East India House, 5 Lime Street, London, E.C.
1852. Wilson, Joseph W., 19 Craven Street, Strand, London, W.C.
1857. Wilson, Robert, Bridgewater Foundry, Patricroft, near Manchester.
1860. Wilson, William, 4 Victoria Street, Westminster, S.W.
1865. Winby, Clifford Etches, Atlas Iron Works, Cardiff.
1867. Winby, Frederick Charles, Atlas Iron Works, Cardiff.
1862. Winby, William Edward, Old Park Iron Works, Wednesbury.
1859. Winter, Thomas Bradbury, 28 Moorgate Street, London, E.C.
1863. Wise, Francis, Chandos Chambers, Buckingham Street, Adelphi, London, W.C.
1865. Woodall, Solomon, Windmill End Boiler Works, near Dudley.
1848. Woodhouse, Henry, London and North Western Railway, Stafford.
1851. Woodhouse, John Thomas, Mining Engineer, Midland Road, Derby.
1858. Woods, Hamilton, Liver Foundry, Ordsal Lane, Salford, Manchester.
1860. Worthington, Samuel Barton, Engineer, London and North Western Railway, Manchester.
1866. Wray, William, Ship Building Yard, Burton Stather, near Brigg.
1866. Wren, Henry, London Road Iron Works, Manchester.
1867. Wright, John Turner, Universe Rope Works, Garrison Street, Birmingham.
1859. Wright, Joseph, Metropolitan Carriage and Wagon Company, Saltley Works, Birmingham.
1860. Wright, Joseph, Neptune Forge, Tipton Green, Dudley.
1863. Wright, Owen, Broadwell Forge, Oldbury, near Birmingham.
1863. Wright, Peter, Railway Wheel Vice and Anchor Works, Dudley.
1865. Wyllie, Andrew, Vauxhall Foundry, Liverpool.
1853. Wymer, Francis W., Surveyor of Steam Vessels, Board of Trade, Greenock.

1861. Yule, William, 102 New Canal, St. Petersburg.

HONORARY LIFE MEMBERS.

1865. Downing, Samuel, LL.D., Museum Building, Trinity College, Dublin.
1847. Fairbairn, William, LL.D., The Polygon, Ardwick, Manchester.
1867. Morin, General Arthur, Director, Conservatoire Impérial des Arts et Métiers, Paris.
1867. Tresca, Henri, Engineer Sub-Director, Conservatoire Impérial des Arts et Métiers, Paris.

ASSOCIATES.

1865. Barker, Frederick, Leeds Iron Works, Leeds.
1867. Blinkhorn, William, London and Manchester Plate Glass Works, Sutton, St. Helen's.
1863. Brockbank, William, 5 Clarence Street, Manchester.
1866. Chadwick, William, Monkbridge Iron Works, Leeds.
1848. Crosby, Samuel, Tenby House, Victoria Road, Aston, Birmingham.
1866. Crossley, John, British Plate Glass Works, Ravenhead, near St. Helen's.
1867. Dewhurst, John Bonny, Bellevue Cotton Mills, Skipton.
1863. Fisher, John, Priory Street, Dudley.
1863. Forster, George Emmerson, Collingwood Chambers, Newcastle-on-Tyne.
1865. Gössell, Otto, 22 Moorgate Street, London, E.C.
1865. Hall, John, 56 King Street, Manchester.
1864. Hornblower, Joseph Wells, 14 Waterloo Street, Birmingham.
1860. Hutchinson, William, Blue Lias Lime Stone Offices, Lyme Regis.
1858. Lawton, Benjamin C., 44 Westgate Street, Newcastle-on-Tyne.
1859. Leather, John Towlerton, Leventhorpe Hall, near Leeds. (*Life Associate.*)
1865. Longsdon, Alfred, 11 New Broad Street, London, E.C.
1860. Manby, Cordy, Tower Street, Dudley.
1867. Neave, William Alexander, 53 St. George's Road, Eccleston Square, London, S.W.
1863. Nichols, William, Midland Copper Works, Guild Street, Burton-on-Trent.
1865. Parry, David, Leeds Iron Works, Leeds.
1864. Parsons, Charles T., Ann Street, Birmingham.
1856. Pettifor, Joseph, Midland Railway, Derby.
1861. Ratcliff, Charles, Wyddrington, Edgbaston, Birmingham.
1863. Rigg, Arthur, The College, Chester.
1867. Robertson, James, 5 Bankside, Southwark, London, S.E.
1867. Roe, Thomas, Jun., Siddals Road, Derby.
1866. Scott, John Peers, 10 Tib Lane, Cross Street, Manchester.
1859. Sherriff, Alexander Clunes, M.P., Great Western Railway, Worcester.
1863. Storey, Thomas R., Bond Court House, Walbrook, London, E.C.
1864. Tennant, John, St. Rollox Chemical Works, Glasgow. (*Life Associate.*)
1864. Thornton, Falkland Samuel, Bradford Street, Birmingham.
1865. Warden, Thomas, Lionel Street, Birmingham.
1848. Warden, William Marston, Edgbaston Street, Birmingham.
1858. Waterhouse, Thomas, Claremont Place, Sheffield.
1867. Watts, William Thomas, 78 Parade, Birmingham.
1866. White, Richard Lewis, Great Western Railway, Swindon.
1862. Whitehead, William, Don Steel Works, Sheffield.
1865. Whitley, Joseph, Bowman Lane, Leeds.
1863. Woolley, John, Marehay Colliery, Ripley, near Derby.

GRADUATES.

1866. Butler, James, Atlas Works, Manchester.
1866. Butler, Thomas Snowden, Kirkstall Forge, Leeds.
1867. Cuss, Nevil John, Great Western Railway, Locomotive Department, Swindon.
1867. Downes, James Charles, Midland Railway, Locomotive Department, Derby.
1867. Flavel, Sidney, Jun., Eagle Foundry, Leamington.
1850. Glydon, George, Spring Hill Tube and Metal Works, Eyre Street, Birmingham.
1867. Hill, Henry Walker, Notintone Place, Sneinton, near Nottingham.
1867. Holland, George, care of John Holland, Contractor, Northwich.
1866. Humphrys, Robert Harry, Deptford Pier, London, S.E.
1867. Jones, George Edward, Horseley Iron Works, Tipton.
1867. Mayhew, Horace, Wigan Coal and Iron Works, Wigan.
1861. Middleton, Henry Charles, Vulcan Iron Foundry, Summer Lane, Birmingham.
1867. Mitchell, John, Swaithe Colliery, Barnsley.
1867. Pearson, John Edward, Spring Colliery, Ince Hall, near Wigan.
1866. Ryland, Frederick, Messrs. Kenrick's Works, Spon Lane, Westbromwich.
1867. Warden, Howard William, Horseley Iron Works, Tipton.
1867. Wright, John Roper, Steel Works, 20 Hampton Street, Birmingham.

PROCEEDINGS.

31 JANUARY, 1867.

The TWENTIETH ANNIVERSARY MEETING of the Members was held in the Lecture Theatre of the Midland Institute, Birmingham, on Thursday, 31st January, 1867; JOHN PENN, Esq., President, in the Chair.

The Minutes of the last General Meeting were read and confirmed.

The Secretary then read the following

ANNUAL REPORT OF THE COUNCIL.

1867.

The Council have great pleasure, on this occasion of the Twentieth Anniversary of the Institution, in congratulating the Members upon the highly satisfactory position and the continued progress of the Institution.

The Financial statement of the affairs of the Institution for the year ending 31st December 1866 shows a balance in the Treasurer's hands of £4152 2*s*. 7*d*. after the payment of the accounts due to that date. The Finance Committee have examined and checked the receipts and payments of the Institution for the last year 1866, and report that the following Balance Sheet rendered by the Treasurer is correct. (*See Balance Sheet appended.*)

The Council report with great satisfaction the large increase in the number of Members that has taken place during the year; the total number of Members of all classes for the year being 728, of whom 2 are Honorary Life Members, 37 are Associates, and 7 are Graduates, being an effective increase of 76 during the year.

The following deceases of Members of the Institution have occurred during the last year 1866:—

John Ashbury,	Manchester.
Charles Green,	Birmingham.
Parkin Jeffcock,	Derby.
Joseph Whitham,	Leeds.

The Council have the pleasure of acknowledging the following Donations to the Library of the Institution during the past year; and also of expressing their thanks to the Donors for the valuable and acceptable additions they have presented. The Council wish to urge on the attention of the Members the important advantage of obtaining a good collection of Engineering Books, Drawings, and Models or Specimens of interest in the Institution, for the purpose of reference by the Members personally or by correspondence; and they trust this desirable object will be promoted by the Members generally, so that by their united aid it may be efficiently accomplished. Members are requested to present copies of their Works to the Library of the Institution.

LIST OF DONATIONS TO THE LIBRARY.

On the Strength of Cast-Iron Pillars, by James B. Francis; from the author.

Report of the Mauritius Inundation Committee; from Mr. James R. Mosse.

Report on Bridle Road and Passes in Canterbury Province, New Zealand, by Edward Dobson; from the author.

Engineer's Report on the Leeds Water Supply, by Edward Filliter; from the author.

Useful Information for Engineers, by William Fairbairn; from the author.

On a Balanced Rudder for Screw Steamers, by W. J. Macquorn Rankine; from the author.

On the most Economical Rates of Expansion in Steam Engines, do. do.

On Saturated Vapours, do. do.

Synopsis of the Described Lepidoptera of North America; from the Smithsonian Institution, Washington.

Report of the Smithsonian Institution for 1864; from the Institution.

Collection of Drawings of the Ecole Impériale des Ponts et Chaussées, Paris; from the Ecole.

Proceedings of the Institution of Civil Engineers; from the Institution.

Proceedings of the French Institution of Civil Engineers; from the Institution.

Bulletin of the French Society for the Encouragement of National Industry; from the Society.

Transactions of the North of England Institute of Mining Engineers; from the Institute.

Report of the British Association for the Advancement of Science; from the Association.

Proceedings of the South Wales Institute of Engineers; from the Institute.

Transactions of the Institution of Engineers in Scotland; from the Institution.

Transactions of the Society of Engineers; from the Society.

Memoirs of the Literary and Philosophical Society of Manchester; from the Society.

Journal of the Hannover Architect and Engineers' Society; from the Society.

Journal of the Royal United Service Institution; from the Institution.

Transactions of the Royal Scottish Society of Arts; from the Society.

Transactions of the Dudley and Midland Geological and Scientific Society; from the Society.

Reports of the Manchester Association for the Prevention of Steam Boiler Explosions; from the Association.

Reports of the Midland Steam Boiler Association; from the Association.

Report of the British Association of Gas Managers; from the Association.

Catalogue of the Manchester Free Reference Library; from the Library.

Journal of the Board of Arts and Manufactures for Upper Canada; from the Board.

Journal of the Society of Arts; from the Society.

The Engineer; from the Editor.

Engineering; from the Editor.

The Mechanics' Magazine; from the Editor.

The Civil Engineer and Architect's Journal; from the Editor.

The London Journal of Arts; from the Editor.

The Artizan Journal; from the Editor.

The Practical Mechanic's Journal; from the Editor.

The Mining Journal; from the Editor.

The Railway Record; from the Editor.

The Steam Shipping Journal; from the Editor.

Specimens of Corroded Plates from Locomotive Boilers; from Mr. William Kirtley.

Specimens of Corroded Plates from Stationary Boilers; from Mr. Edward B. Marten.

Specimens of improved Tool and Holder for turning and planing; from Mr. W. Ford Smith.

The Council have great satisfaction in referring to the number and character of the Papers that have been brought before the meetings during the past year, and the practical value and interest of the communications and the discussions that took place upon them, which form a valuable addition to the Proceedings of the Institution. The Council request the special attention of the Members to the importance of their aid and co-operation in carrying out the objects of the Institution and maintaining its advanced position, by contributing papers on Engineering subjects that have come under their observation, and communicating the particulars and results of executed works and practical experiments that may be serviceable and interesting to the Members; and they invite communications upon the subjects in the list appended and other subjects advantageous to the Institution.

The following Papers have been read at the Meetings during the last year:—

Description of an improved Chronometric Governor for Steam Engines &c.; by Mr. C. William Siemens, of London.

On an improved construction of Wrought-Iron Turntable; by Mr. William Baines, of Soho.

On the Corrosion of Locomotive Boilers, and the means of Prevention; by Mr. William Kirtley, of Derby.

On an improved construction of Lock and Key; by Mr. J. Beverley Fenby, of Birmingham.

On the Proof of Guns by Measurement, with description of the Instrument employed; by the President.

Description of an improved Reversing Rolling Mill; by Mr. John Ramsbottom, of Crewe.

On Steam Boiler Explosions and their records, and on Inspection as a means of Prevention; by Mr. Edward B. Marten, of Stourbridge.

Description of the Removing and Replacing of the Iron Columns in a Cotton Mill; by Mr. William Fairbairn, of Manchester.

On an improved mode of Manufacture of Steel Tyres; by Mr. John Ramsbottom, of Crewe.

On Machinery for the Preparing and Spinning of Cotton; by Mr. John Platt, of Oldham.

Description of the Manchester Water Works; by Mr. John Frederic Bateman, of London.

On Sellers' Self-Adjusting Injector, and other improvements on Giffard's Injector; by Mr. John Robinson, of Manchester.

Description of a Curvilinear Shaping Machine; by Mr. Francis W. Webb, of Bolton.

On an improved Tool and Holder for turning and planing; by Mr. W. Ford Smith, of Manchester.

The Council have particular pleasure in referring to the great success and interest of the Annual Meeting of the Institution that was held in Manchester last summer, and in expressing their special thanks to the authorities of the Mechanics' Institution, Mr. Charles P. Stewart, and the other local Members, for the very excellent arrangements and the handsome reception given to the Members on the occasion; and also their thanks to the railway authorities for the special arrangements granted for the excursions; and to the proprietors of the works that were so liberally thrown open to the inspection of the Members, for the valuable opportunity afforded to the Members for seeing their works. The Council refer particularly to the great advantage afforded to the Members in the admirable opportunity provided them for visiting the Crewe Steel Works, the Cotton Machinery Works and Cotton Mills, and the Locomotive and Railway Carriage Works; and they offer their special acknowledgments to the President, Mr. Whitworth, for the great pleasure afforded to the Members by their visit to his Works, and by his exceedingly kind and hospitable reception of them at his residence at Stancliffe Hall. The Council look forward with confidence to the important advantages arising from the continuance of these Annual Meetings in different localities, from the facilities afforded by them for the personal communication of the Members in different districts, and from the opportunities of visiting the important Engineering Works that are so liberally thrown open to their inspection on those occasions.

The President, Vice-Presidents, and five of the Members of the Council in rotation, go out of office this day, according to the rules of the Institution; and the ballot will be taken at the present Meeting for the election of the Officers and Council for the ensuing year.

SUBJECTS FOR PAPERS.

STEAM ENGINE BOILERS, particulars of construction—form and extent of heating surface—relative value of radiant surface and flue surface in effect and economy—cost—consumption of fuel—evaporation of water—pressure of steam—density and heat of steam—superheated steam, simple or mixed with common steam—pressure gauges—safety valves—water gauges—explosion of boilers, and means of prevention—effects of heat on the metal of boilers, low-pressure and high-pressure—steel boilers—cast-iron boilers—welded boilers—incrustation of boilers, and means of prevention—corrosion of boilers, and means of prevention—effects of surface condensers on the metal of boilers—evaporative power and economy of different kinds of fuel, coal, wood, charcoal, peat, patent coal, and coke—moveable grates, and smoke-consuming apparatus, facts to show the best plan, and results of working—plans for heating feed water—mode of feeding—use of injector—circulation of water.

STEAM ENGINES—expansive force of steam, and best means of using it—power obtained by various plans—comparison of double and single cylinder engines—combined engines—compound cylinder engines—comparative advantages of direct-acting and beam engines—engines for manufacturing purposes—horizontal and vertical—condensing and non-condensing—injection and surface condensers—air pumps—governors—valves—bearings, &c.—improved expansion gear—indicator diagrams from engines, with details of useful effect, consumption of fuel, &c.—contributions of indicator diagrams for reference in the Institution.

PUMPING ENGINES, particulars of various constructions—Cornish engines, beam engines with crank and flywheel, direct-acting engines with and without flywheel—size of steam cylinder and degree of expansion—number and size of pumps, and strokes per minute—speed of piston—pressure upon pump—effective horse power and duty—comparison of double-acting and single-acting pumping engines—construction of pumps—plunger pumps—bucket pumps—particular details of different valves—india-rubber valves, durability and results of working—diagrams of lift of valves—application of pumps—fen-draining engines—comparative advantages of scoop wheels and centrifugal pumps, lifting trough, &c.—details of pit work of pumping engines at mines.

BLAST ENGINES, best kind of engine—size of steam cylinder, strokes per minute, and horse power—details of boilers—size of blowing cylinder, and strokes per minute—pressure of blast, and means of regulation—construction of valves—improvements in blast cylinders—rotary blowing machines—indicator diagrams from air main and steam cylinder.

Marine Engines, power of engines in proportion to tonnage—different constructions of engines, double cylinder engines, trunk engines—three-cylinder engines—use of steam jackets—dynamical effect compared with indicator diagrams—comparative economy and durability of different boilers, tubular boilers, flat-flue boilers, &c.—brine pumps, and means of preventing deposit—salinometers—weight of machinery and boilers—kind of paddle wheels—speed obtained in British war steamers, in British merchant steamers, and in Foreign ditto, with particulars of the construction of engines with paddle wheels, &c.—screw propellers, particulars of different kinds, improvements in form and position, number of arms, material, means for unshipping, bearings, horse power applied, speed obtained, section of vessel—governors and storm governors.

Rotary Engines, particulars of construction and practical application—details of results of working.

Locomotive Engines, particulars of construction, details of experiments, and results of working—consumption of fuel—relative value and evaporative duty of coke and coal—consumption of smoke—use of wood and construction of spark arresters—heating surface, length and diameter of tubes—material of tubes—experiments on size of tubes and blast pipe—construction of pistons, valve gear, expansion gear, &c.—indicator diagrams—expenses of working and repairs—means of supplying water to tenders—locomotives for steep gradients and sharp curves—distribution of weight on wheels.

Agricultural Engines, details of construction and results of working—duty obtained—application of machinery and steam power to agricultural purposes—barn machinery—field implements—traction engines, particulars of performance and cost of work done.

Caloric Engines—engines worked by gas, or explosive compounds—electro-magnetic engines—particulars and results.

Hydraulic Engines, particulars of application and working—pressure of water—construction and arrangement of valves, relief valves—construction of joints—hydraulic rams.

Water Wheels, particulars of construction and dimensions—form and depth of buckets—head of water, velocity, percentage of power obtained—turbines, construction and practical application, power obtained, comparative effect and economy—transmission of power to distant points.

Wind Mills, particulars of construction—number of sails, surface and form of sails—velocity, and power obtained—average number of days' work per annum.

Corn Mills, particulars of improvements—power employed—application of steam power—results of working with an air blast and ring stones—crushing by rolls before grinding—advantages of regularity of motion.

SUGAR MILLS, particulars of construction and working—results of application of the hydraulic press in place of rolls—application of steam and water for extracting the last portion of saccharine matter—construction and working of evaporating pans.

OIL MILLS, facts relating to construction and working, by stampers, by screw presses, and by hydraulic presses—particulars of crushing rollers and edge stones.

COTTON MILLS, information respecting the construction and arrangement of the machinery—power employed, and application of power—cotton presses, mode of construction and working, power employed—improvements in spinning, carding, and winding machinery, &c.

CALICO-PRINTING AND BLEACHING MACHINERY, particulars of improvements.

WOOL MACHINERY, carding, combing, roving, spinning, &c.

FLAX MACHINERY, manufacture of flax, china grass, and other fibrous materials, both in the natural length of staple and when cut.

ROPE-MAKING MACHINERY—hemp and wire ropes, comparative strength, durability, and cost—steel wire ropes—transmission of power by ropes, percentage of loss, distance, wear of ropes, &c.

SAW MILLS, particulars of construction—mode of driving—power employed—particulars of work done—best speeds for vertical and circular saws—form of saw teeth—saw mills for cutting ship timbers—veneer saws—endless band saws.

WOOD-WORKING MACHINES, morticing, planing, rounding, and surfacing—copying machinery.

GLASS MACHINERY—manufacture of plate and sheet glass—construction of heating furnaces, annealing kilns, &c.—grinding and polishing machinery.

LATHES, PLANING, BORING, DRILLING, SLOTTING, AND SHAPING MACHINES, &c., particulars of improvements—description of new self-acting tools—engineers' tools—files and file-cutting machinery.

ROLLING MILLS, improvements in machinery for making iron and steel—mode of applying power—use of steam hammers—piling of iron—plates—fancy sections—arrangement and speed of rolls—length of bar rolled—manufacture of rolled girders—rolling of armour plates—reversing rolls.

STEAM HAMMERS, improvements in construction and application—friction hammers—air hammers.

RIVETTING, PUNCHING, AND SHEARING MACHINES, worked by steam or hydraulic pressure—direct-acting and lever machines—portable machines—comparative strength of drilled and punched plates—rivet-making machines.

STAMPING AND COINING MACHINERY, particulars of improvements, &c.

LOCKS, and lock-making machinery—iron safes.

PAPER-MAKING AND PAPER-CUTTING MACHINES, new materials and results.

Printing Machines, particulars of improvements, &c.—machines for printing from engraved surfaces—type composing and distributing machines.

Water Pumps, facts relating to the best construction, means of working, and application—velocity of piston—construction, lift, and area of valves.

Air Pumps, facts relating to the best construction, means of working, and application—velocity of piston—construction, lift, and area of valves.

Hydraulic Presses, facts relating to the best construction, means of working, and application—economical limit of pressure.

Rotary and Centrifugal Pumps, ditto ditto ditto.

Fire Engines, hand and steam, ditto ditto ditto.

Sluices and Sluice Cocks, worked by hand or hydraulic power, ditto.

Cranes, steam cranes, hydraulic cranes, pneumatic cranes, travelling cranes.

Lifts for raising railway wagons—hoists for warehouses—safety apparatus.

Toothed Wheels, best construction and form of teeth—results of working—power transmitted—method of moulding—strength of iron and wood teeth.

Driving Belts and Straps, best make and material, leather, gutta-percha, vulcanised india-rubber, rope, wire, chain, &c.—comparative durability, and results of working—power communicated by certain sizes—frictional gearing, construction and driving power obtained—friction clutches—shafting and couplings.

Dynamometers, construction, application, and results of working.

Decimal Measurement—application of decimal system of measurement to mechanical engineering work—drawing and construction of machinery, manufactures, &c.—construction of measuring instruments, gauges, &c.

Strength of Materials, facts relating to experiments, and general details of the proof of girders, &c.—girders of cast and wrought iron, particulars of different constructions, and experiments on them—rolled girders—best forms and proportions of girders for different purposes—best mixture of metal—mixtures of wrought iron with cast.

Durability of Timber of various kinds—best plans for seasoning and preserving timber and cordage—results of various processes—comparative durability of timber in different situations—experiments on actual strength of timber.

Corrosion of Metals by salt and fresh water, and by the atmosphere, &c.—facts relating to corrosion, and best means of prevention—means of keeping ships' bottoms clean—galvanic action, nature, and preventives.

Alloys of Metals, facts relating to different alloys.

Friction of Various Bodies, facts relating to friction under ordinary circumstances—facts on increase of friction by reduction of surface in contact—friction of iron, brass, copper, tin, wood, &c.—proportion of weight to rubbing surface—best forms of journals, and construction of axleboxes—wood bearings—water axleboxes—lubrication, best materials, means of application, and results of practical trials—best plans for oil tests—friction breaks.

IRON ROOFS, particulars of construction for different purposes—durability in various climates and situations—comparative cost, weight, and durability—roofs for slips of cast-iron, wrought-iron, timber, &c.—best construction, form, and materials—details of large roofs, and cost.

FIRE-PROOF BUILDINGS, particulars of construction—most efficient plan—results of trials.

CHIMNEY STACKS of large size—particulars, form, mode of building, cheapest construction, &c.—force of draught, and temperature of current.

BRICKS, manufacture, durability, and strength—hollow bricks, fire bricks, and fire clay—perforated bricks, cost of manufacture, and advantages—dry-clay bricks—machines for brick making—burning of bricks.

GAS WORKS, best form, size, and material for retorts—construction of retort ovens—quantity and quality of gas from different coals—oil gas, cheapest mode of making—water gas, &c.—improvements in purifiers, condensers, and gasholders—wet and dry gas meters—self-regulating meters—pressure of gas, gas exhauster—gas pipes, strength and durability, and construction of joints—proportionate diameter and length of gas mains, and velocity of the passage of gas—experiments on ditto, and on the friction of gas in mains, and loss of pressure—lighting railway trains with gas.

WATER WORKS, facts relating to water works—application of power, and economy of working—proportionate diameter and length of pipes—experiments on the discharge of water from pipes, and friction through pipes—strength and durability of pipes, and construction of joints—penetration of frost in different climates—relative advantages of stand pipes and air vessels—sluices and self-acting valves—machinery for working sluices—water meters, construction and working.

WELL SINKING AND ARTESIAN WELLS, facts relating to—boring tools, construction and mode of using.

TUNNELLING MACHINES, particulars of construction, and results of working.

COFFER DAMS AND PILING, facts relating to construction—cast-iron sheet piling.

PIERS, fixed and floating, and pontoons, ditto ditto.

PILE DRIVING APPARATUS, particulars of improvements—use of steam power—particulars of working—weight of ram and height of fall, total number of blows required—vacuum piles—compressed air system—screw piles.

DREDGING MACHINES, particulars of improvements—application of dredging machines—power required and work done.

DIVING BELLS AND DIVING DRESSES, facts relating to the best construction.

LIGHTHOUSES, cast-iron and wrought-iron, ditto ditto.

SHIPS, iron and wood—details of construction—lines, tonnage, cost per ton—water ballast—steel masts and yards, and wire-rope rigging—comparative strength and advantage of iron and wood ships—arrangements for docking and repairing ships.

GUNS, cast-iron, wrought-iron, and steel—manufacture and proof—rifling—manufacture of shot and shells.

MINING OPERATIONS, facts relating to mining—modes of working and proportionate yield—coal-cutting machines—means of ventilating mines—use of ventilating machinery—safety lamps—lighting mines by gas—drainage of mines—sinking pits—mode of raising materials—safety guides—winding machinery—underground conveyance—stone-breaking machines—mode of breaking, pulverising, and sifting various descriptions of ores.

BLASTING, facts relating to blasting under water, and blasting generally—use of gun-cotton, &c.—effects produced by large and small charges of powder—arrangement of charges.

BLAST FURNACES, shape and size—consumption of fuel—burden, make, and quality of metal—pressure of blast—horse power required—economy of working—improvements in manufacture of iron—comparative results of hot and cold blast—increased temperature of blast—construction and working of hot-blast ovens—pyrometers—construction of tuyeres—means and results of application of waste gas from close-topped and open-topped furnaces—preparation of materials for furnace and mode of charging.

PUDDLING FURNACES, best forms and construction—worked with coal, charcoal, &c.—application of machinery to puddling.

HEATING FURNACES, best construction—consumption of fuel, and heat obtained.

CONVERTING FURNACES, construction of furnaces—manufacture of steel—casehardening, &c.—converting materials employed.

SMITHS' FORGES, best construction—size and material—power of blast—hot blast, &c.—construction of tuyeres.

SMITHS' FANS AND FANS generally, best construction, form of blades, &c.—facts relating to power employed and percentage of effect produced—pressure and quantity of air discharged—size and construction of air mains—mechanical ventilation and warming of public buildings.

COKE AND CHARCOAL, particulars of the best mode of making, and construction of ovens, &c.—open coking, mixtures of coal slack and other materials—evaporative power of different varieties—peat, manufacture of compressed peat.

RAILWAYS, construction of permanent way—section of rails, and mode of manufacture—mode of testing rails—experiments on rails, deflection, deterioration, and comparative durability—material and form of sleepers, size, and distances—improvements in chairs, keys, and joint fastenings—permanent way for hot climates.

Switches and Crossings, particulars of improvements, and results of working.

Turntables, particulars of various constructions and improvements—engine turntables.

Signals for stations and trains, and self-acting signals.

Electric Telegraphs, improvements in construction and insulation—coating of wires—underground and submarine cables—mode of laying, and machinery employed.

Railway Carriages and Wagons, details of construction—proportion of dead weight.

Breaks for carriages and wagons, best construction—self-acting breaks—continuous breaks.

Buffers for carriages, &c., and station buffers—different constructions and materials.

Couplings for carriages and wagons—safety couplings.

Springs for carriages, &c.—buffing, bearing, and draw springs—range, and deflection per ton—particulars of different constructions and materials, and results of working.

Railway Wheels, wrought-iron, cast-iron, and wood—particulars of different constructions, and results of working—comparative expense and durability—wrought-iron and steel tyres, comparative economy and results of working—mode of fixing tyres—manufacture of weldless tyres, and solid wrought-iron wheels.

Railway Axles, best description, form, material, and mode of manufacture.

The Papers are to be written in the third person, on foolscap paper, on one side only of each page, leaving a clear margin of an inch width on the left side. In the subjects of the papers, extracts from printed publications and questions of patent right or priority of invention are not admissible.

The Diagrams to be on a large scale and strongly coloured, so as to be clearly visible to the meeting at the time of reading the paper. Enlarged details to be added for the illustration of any particular portions, drawn full size or magnified, with the different parts strongly coloured in distinctive colours. Several explanatory diagrams drawn roughly to a large scale in dark pencil lines and strongly coloured are preferable to a few small-scale finished drawings. The scale of each diagram to be marked upon it.

INSTITUTION OF MECHANICAL ENGINEERS.

BALANCE SHEET.

For the year ending 31*st December*, 1866.

Cr.	£	s.	d.
By Balance 31st December, 1865	3474	3	10
„ Subscriptions from 27 Members in arrear . . .	81	0	0
„ ditto from 1 Associate in arrear	3	0	0
„ ditto from 589 Members for 1866	1767	0	0
„ ditto from 27 Associates for 1866	81	0	0
„ ditto from 5 Graduates for 1866	10	0	0
„ ditto from 12 Members in advance for 1867 . .	36	0	0
„ ditto from 2 Life Members	60	0	0
„ Entrance Fees from 79 New Members	158	0	0
„ ditto from 3 New Associates	6	0	0
„ ditto from 3 New Graduates	3	0	0
„ Sale of Extra Reports	18	6	0
„ Interest from Bank	238	15	5
	£5936	5	3

Dr.				£	s.	d.
To Printing and Engraving Reports of Proceedings	896	19	0			
Less Authors' copies of papers, repaid	29	3	6	867	15	6
„ Stationery and Printing				71	13	5
„ Office Expenses and Petty Disbursements . . .				75	5	3
„ Coals, Gas, and Water				23	5	10
„ Expenses of Meetings				51	10	1
„ Fittings and Repairs				4	12	7
„ Travelling Expenses				29	3	9
„ Parcels				5	7	10
„ Postages				82	15	2
„ Salaries				450	0	0
„ Insurance				2	8	3
„ Rent and Taxes				120	5	0
Balance 31st December, 1866				4152	2	7
				£5936	5	3

(Signed) EDWARD JONES,
WALTER MAY, } Finance Committee.

31*st January*, 1867.

MEMOIRS

OF MEMBERS DECEASED IN 1866.

John Ashbury was born on 31st January 1806, and resided with his uncle at Winton near Manchester, until he was about nineteen years of age, when he bound himself apprentice to a wheelwright in Manchester. His energy and industry soon obtained for him the position of a first-class workman both in wood and iron. About 1840 he began business in a small way in Manchester as a wheelwright; and having been entrusted with the building of a few coal wagons for the Manchester and Leeds Railway, he subsequently entered upon the building of railway wagons, and in 1847 commenced the large works at Openshaw near Manchester for building railway carriages and wagons. A forge, rolling mill, and puddling furnaces were afterwards added, for making iron and for the manufacture of general railway plant. The works became ultimately so extensive and complete that in 1862 a railway goods wagon was entirely constructed in a single day for the International Exhibition (with the exception only of the steel springs), the timber work being cut from the log and the whole of the ironwork made from the pig iron; the work was commenced at 6 a.m., and the wagon was finished, loaded with goods, and sent away to London at 7 p.m. the same day. The works were disposed of to a Limited Liability Company in the year 1862. Mr. Ashbury died at his residence in London on 2nd September 1866 at the age of sixty, after a short illness. He was a Member of this Institution from 1848.

Charles Green was born at Birmingham in 1798, and having served his apprenticeship to the jewellery and gold and silver plating business he afterwards carried on that business for some years, during which time he invented the solid-drawn gold "key-pipe" for watch keys, by drawing a weldless or solid tube out of a flat circular disc of gold: these key-pipes having previously been made by drawing a tube out of a narrow flat strip of metal, which then required soldering along the whole length of the joint, the soldering process occupying a much longer time than the drawing of the tube. After trying experiments with other metals, he succeeded in effecting the drawing of solid brass tubes for locomotive and marine boilers; and in 1841 he started works in Birmingham for the manufacture of the solid-drawn brass boiler tubes, which ultimately came into general use in place of the previous brazed tubes. He was elected a Member of this Institution in 1848, and died at Birmingham on 25th March 1866 in the sixty-eighth year of his age.

Parkin Jeffcock was born on 27th October 1829 at Cowley Manor near Sheffield; and in 1850 was articled to Mr. George Hunter at Belmont near Durham, to learn the profession of colliery viewer, and afterwards to Mr. J. T. Woodhouse at Moira in Leicestershire, with whom he subsequently entered into partnership at Derby in 1857 as a mining engineer. In this capacity he was professionally concerned with many important collieries in the midland counties and in the South Yorkshire coalfield, with which he thereby became intimately acquainted. His death occurred on 13th December 1866 in the explosion at the Oaks Colliery near Barnsley, one of the collieries under his charge. A great explosion having taken place at this colliery on the previous day, causing very serious loss of life, Mr. Jeffcock had descended with others for the purpose of endeavouring to recover the bodies of the dead, and to arrange for restoring the ventilation of the mine; but a second and third explosion following shortly after their descent, they themselves lost their lives in the attempt. The fiery nature of the Barnsley Thick coal, in which the workings of the Oaks Colliery were situated, and the dangers attending its working even with the strictest use of safety lamps, were described in a paper on the coal and iron mining of South Yorkshire, contributed by Mr. Jeffcock to this Institution, (see Proceedings Inst. M. E. 1862 page 79). He was elected a Member of the Institution in 1855.

Joseph Whitham was born at Kirkstall near Leeds in 1833; and his father having been previously an engineer and millwright established in 1840 the Perseverance Iron Works in Leeds, to which he and his brother succeeded in 1854, as makers of engines, boilers and other machinery, and as iron manufacturers. He was elected a Member of this Institution in 1859, and died after a very short illness on 12th February 1866 at the age of thirty-two.

The Chairman moved that the Report of the Council be received and adopted, which was passed.

The Chairman announced that the Ballot Lists had been duly opened, and the following Officers and Members of Council were found to be elected for the ensuing year:—

PRESIDENT.

John Penn,	London.

VICE-PRESIDENTS.

Charles F. Beyer,	Manchester.
William Clay,	Liverpool.
Robert Hawthorn,	Newcastle-on-Tyne.
Sampson Lloyd,	Wednesbury.
Henry Maudslay,	London.
John Ramsbottom,	Crewe.

COUNCIL.

Alexander Allan,	Worcester.
John Anderson,	Woolwich.
Frederick J. Bramwell,	London.
Charles Cochrane,	Dudley.
C. William Siemens,	London.

PAST-PRESIDENTS.

Ex-officio permanent Members of Council.

Sir William G. Armstrong,	Newcastle-on-Tyne.
William Fairbairn,	Manchester.
James Kennedy,	Liverpool.
Robert Napier,	Glasgow.
Joseph Whitworth,	Manchester.

COUNCIL.

Members of Council remaining in office.

Edward A. Cowper,	London.
John Fernie,	Leeds.
Sir Charles Fox,	London.
George Harrison,	Birkenhead.

Edward Humphrys,	London.
Edward Jones,	Birmingham.
Walter May,	Birmingham.
W. Montgomerie Neilson,	Glasgow.
John Robinson,	Manchester.
Charles P. Stewart,	Manchester.

TREASURER.

Henry Edmunds,	Birmingham.

SECRETARY.

William P. Marshall,	Birmingham.

The following New Members were also elected :—

MEMBERS.

George Allibon,	London.
George Bell,	Bolton.
William Duff Bruce,	Lucknow, India.
Daniel Campbell,	London.
James Easton,	Gateshead.
William Henry Gauntlett,	Middlesbrough.
George Clementson Greenwell,	Stockport.
William Hopper,	Moscow, Russia.
Samuel Horrocks,	Sheffield.
George Douglas Hughes,	Nottingham.
William Inglis,	Manchester.
Charles William Lancaster,	London.
Thomas Morgans,	Taunton.
John D. Napier,	Birkenhead.
William Powell,	Portland.
Daniel Rowlinson Ratcliff,	Liverpool.
George Ratliffe,	Crewe.
Henry Fullwood Rose,	Wednesbury.
Thomas Rose,	Manchester.
Millin Selby,	Vladimir, Russia.

Joseph Lee Thomas	Douglas, Isle of Man.
Frederick Charles Winby	Cardiff.
John Turner Wright	Birmingham.

ASSOCIATE.

James Robertson	London.

GRADUATES.

George Edward Jones	Tipton.
Horace Mayhew	Wigan.
John Roper Wright	Sheffield.

The following paper was then read :—

DESCRIPTION OF THE PAYING-OUT AND PICKING-UP MACHINERY EMPLOYED IN LAYING THE ATLANTIC TELEGRAPH CABLE.

BY MR. GEORGE ELLIOT, OF LONDON.

The Atlantic Telegraph Cable expedition of 1866 was twofold in its purpose, the first object being to lay a new cable, and the second to recover and complete the one commenced and lost in the unsuccessful attempt of the previous year. The general arrangements on board the *Great Eastern* steamship, which was employed for the purpose on both occasions, were similar in both years; but the knowledge and experience which had been so dearly bought in 1865 rendered necessary many improvements and alterations in the detail of the apparatus employed.

The cable itself was coiled in three circular wrought-iron tanks, which were built on the main deck of the ship, as shown in Figs. 1, 2, and 3, Plate 1, which represent a general plan and longitudinal and transverse sections of the vessel. The foremost tank A occupied the space which had previously been the forecargo space; and the after tank C was placed in what had been the aftercargo space. The middle tank B occupied what had been the second dining saloon; and the funnel (shown by the dotted lines in Fig. 2) from the pair of boilers in that position was removed for the purpose, those boilers being thrown out of work during the expedition. The whole of the fittings in these spaces had been removed, and each of the tanks was stayed to the sides of the ship by two flat frames of iron, built on angle-iron framing, thus securing the tanks in the most substantial manner. The deck had also been shored underneath by baulk timbers, which were carried through from deck to deck down to the bottom of the ship.

The fore tank was 51 ft. 6 ins. diameter, the middle tank 58 ft. 6 ins., and the after tank 58 ft. 0 ins.; they were all of a uniform depth of 20 ft. 6 ins., and similarly constructed in all respects. The bottoms were ½ inch thick, lap-jointed; and the sides were ⅝ inch thick in the lower half, and ½ inch in the upper half. The sides were butt-jointed, so as to present a perfectly smooth surface inside; and the bottoms were covered with a thin wood floor to receive the cable. As it was of vital importance that the cable should be kept always under water, to prevent depreciation of the gutta-percha coating, and also to afford the only means of effectually testing its electrical condition, these tanks were carefully made water-tight. In paying out the cable, the water in the tanks was kept somewhat below the level of the top flake, and required to be lowered during the paying out; for this purpose each tank was supplied with discharge valves, and as the bottoms of the coils were above the water line of the ship, as shown in Fig. 2, it was only necessary to open these valves in order to allow the tanks to discharge themselves completely.

The coiling of the cable into the tanks, out of the hulks by which it was brought from the Telegraph Construction and Maintenance Works at Greenwich to the *Great Eastern* at Sheerness, was effected in the following manner. The cable was brought up over the side of the ship from the hulk, upon wheels which guided it on to a large deep-grooved wheel driven by steam power; on the tread of this wheel ran a small jockey wheel or roller, pressing the cable down into the groove of the large wheel, so as to give sufficient friction for enabling the wheel to draw up the cable from the hulk. The coiling commenced from the outside of the tank, the end being previously triced up above the tank, leaving a clear end for splicing and testing. The first turn of the cable was carefully laid round the outside of the tank, and the next was laid back close up against the previous turn, and so on until a perfectly flat flake or layer was laid into the eye of the coil, which was left about 9 ft. 6 ins. diameter. The cable was then led out direct to the outside of the tank, across the coils already laid; and another flake was commenced precisely similar to the first, this process being continued until the tank was filled. The direction of lay-out of the cable from the end of one flake to the beginning of the next was tangential to the circle of the eye of the coil, as shown at D in the plan, Fig. 1; and the portion of cable crossing the coils was protected from the weight of the coils above by wood battens laid on each side of it, about 3 inches wide and 1 inch thick with the edges rounded. When the coiling down of the cable into the tanks was finished, eyes were fitted into the centre of each coil, which were telescopic in their construction, so that as the cable was paid out the eyes could be lowered from time to time. Men were stationed in the tanks for the purpose of keeping the cable always clear during the paying out.

In paying out the cable it was passed up to the hatch over the centre of the coil, and carried over a large wheel E about 4 feet diameter, as shown in the enlarged longitudinal section, Fig. 4, Plate 2. The cable was then carried in a trough F about 2 feet wide, made of sheet iron, leading to the paying-out machinery; this trough was fitted with rollers at about 10 or 12 feet intervals to relieve the cable from friction in passing along, until it reached the paying-out machinery, which was placed in the stern of the ship, slightly to the port side.

The length of cable in the after tank was 840 knots (1 knot = 6084 feet = 1·15 statute mile), in the middle tank 865 knots, and in the fore tank 671 knots; and the entire length of 2376 knots was joined up into one continuous length of cable before the laying was commenced. The size of the cable was $1\frac{1}{8}$ inch diameter, and its weight 31 cwts. per knot in air, and $14\frac{3}{4}$ cwts. per knot when immersed in water; the breaking strain was 8·10 tons, equal to eleven times its weight in water per knot, so that the cable would just bear its own weight in 11 knots depth of water.

Paying-Out Machinery.—In the paying-out machinery the chief object to be attained was to supply some means of checking the cable in the most regular manner possible while passing out of the ship, and also of keeping it in a state of constant tension; and it was required that the amount of this tension should be at all times known, and that it should be regulated by the depth of the water in each particular part of the ocean, and also to some extent by the speed of the ship.

The most important feature is the arrangement by which it was rendered impossible that more than a certain strain should be kept upon the cable during the paying out. A less strain would only involve a slight loss of cable; but any increased strain might possibly damage or even destroy it. The cable on entering the paying-out machinery was passed over a series of six deep-grooved wheels, each about 3 feet diameter, one of which is shown in side and end elevation at G in Figs. 7 and 8, Plate 3. On the shaft of each wheel G was fixed a friction wheel H of the same diameter, to which was fitted a friction strap lined with wood and tightened by a weight on a lever, as shown in Fig. 7; to prevent any unnecessary wear, this friction wheel ran in a tank of water K. Above each of the grooved carrying wheels was a jockey wheel J about 14 inches diameter, pressing the cable L down into the groove of the carrying wheel G, and hooped with an india-rubber tyre to form a soft cushion, so that no damage might be done to the cable. The jockey wheel was also fitted with a small friction wheel M having a wrought-iron strap adjustable by a screw. Any one of the jockey wheels could be lifted up, so as to allow the cable to slip freely through the groove in the carrying wheel; or in case of necessity the whole set of jockey wheels could be raised at once by a man stationed at a large hand wheel, like an ordinary ship's steering wheel, turning the longitudinal shaft N which lifted up each jockey wheel by a chain winding upon the shaft. In practice there were generally about four of these wheels kept at work, but the machine was made with six in case of need.

After the cable had passed through this part of the machinery, called for distinction the Jockey Gear, and had thereby been subjected to a slight amount of strain, it was led to the main Paying-Out Drum P, shown in side elevation in Fig. 9, Plate 4, and in end elevation in Fig. 10, Plate 5. The cable L entered on the underside of the drum, Fig. 9, and was passed four times round, as a rope is passed round a capstan, and for the same purpose of getting a firm hold upon it. Just above the point at which the cable was led on, a knife-guide Q was placed for fleeting or slipping sideways the coils already on the drum, so as to leave a clear lead-on for the fresh cable; this guide was adjustable in both directions with screws, like a slide-rest on a lathe. The shaft S of the drum was carried through on each side, one end being fitted with a coupling R, which will be referred to afterwards in connection with the picking-up arrangements adapted to this machine; and on the other end were fitted the main friction breaks T T.

These Self-Adjusting Friction Breaks were invented by the late Mr. Appold, and it is interesting to note that they were the identical breaks used in the first attempt to lay the Atlantic cable in 1857. The break wheels themselves T T, Figs. 9 and 10, of which there were two on the shaft, were 4 ft. 6 ins. diameter, and 12 inches wide on the tread, which was turned a little convex. On each wheel was fitted a wrought-iron strap lined with wood, and a screw adjustment U admitted of any required amount of friction being obtained. On the top of each break strap was a lug, to which a long rod V was fastened, leading to the top of a bell-crank lever X with arms in the proportion of 1½ to 1; and to the long arm of this lever was suspended a rod carrying a number of weights W, which were removable at pleasure for adjusting the strain. The rod was continued below the weights, and had a piston attached to it working loosely in a water cylinder, to prevent any sudden jerking action from coming on the break. By screwing up the adjustment U, the break was made to have sufficient friction for lifting the weights on the suspension rod.

In order to render the break self-adjusting, so that it should relieve itself whenever binding too hard, the break strap was cut through, and the ends were attached to a lever A in the manner shown in Fig. 9, the lower extremity of the lever being free to move in a slot cut in the stationary bracket B. When the break was binding too hard, so that it began to lift the weight W too high, the break strap consequently travelled round and brought the lever A into the position shown dotted. The attachment of the one end of the break strap at the extremity of the lever moved then through an arc of a larger radius than the attachment of the other end of the strap; and the result was therefore equivalent to lengthening the break strap and slackening the break off the surface of the wheel, causing the weight W to fall back instantly to its original position. The consequence of this action was that when the break was at work the lever A kept the strap just tight, and the weight W continued just oscillating. The two break wheels T T, placed side by side on the drum shaft, Fig. 10, were both fitted precisely alike throughout.

Near the end of the bell-crank lever X, Fig. 9, a chain was attached leading to a wheel Y overhead; and from a larger wheel on the same shaft another chain led to a barrel on a winch Z. A man standing at this winch by turning the hand-wheel could immediately take all the weight off the breaks T T. The whole of this paying-out machine was made double, so that in case of any mishap there might be no delay, but the cable might at once be removed from one drum to the other. This provision however fortunately proved to be needless, as throughout the expedition there was no failure in any part of the machinery, its action having been in every particular perfect.

The cable having by these means been sufficiently checked was passed over the stern wheel A, Fig. 4, into the sea; and on its way the actual strain was measured by a Dynamometer placed at D, consisting of the following arrangement. Immediately on the cable leaving the paying-out drum P it passed over a wheel H, and at a distance of 23 ft. 6 ins. over another similar wheel I; and in the centre between these two wheels the dynamometer D was fixed, which is shown in Figs. 11 and 12, Plate 5. It consisted of a wheel D weighted to a particular amount and riding upon the cable L, being guided in a fixed vertical frame by rollers A A. The amount of deflection evidently varies according to the strain on the cable, and the strain was calculated from the formula obtained by the ordinary resolution of forces, namely $S = \frac{l}{4d} W$ approximately; where $S =$ strain, and $W =$ weight of dynamometer wheel D, both in the same terms; $l =$ distance between centres of carrying wheels H and I, Fig. 4, and $d =$ deflection of cable. The values of d or amounts of deflection were calculated for all strains from 7 cwts. up to 40 cwts., and a scale B was affixed to the instrument with an index C carried upon the wheel D; so that the strain could immediately be read off at all times by simple inspection. The total weight of the wheel D and its suspended weight F was 426 lbs.; and the rod carrying the weight F was continued down to a piston G working freely in a cylinder of water, to prevent any sudden jerks of the dynamometer. The ordinary strain in paying out was found to vary from 10 to 12 or 14 cwts., and at no time exceeded 16 cwts.

The paying-out drum was also supplied with steam power for reversing its action and picking up the cable, should any fault occur requiring such an operation. This constituted one of the most important improvements over the arrangements of the 1865 expedition, in which it had been necessary to hand the cable along the side of the ship from the paying-out machinery in the stern to the picking-up machinery in the bow, on any occasion of requiring to haul in the cable; and it was during this hazardous process that the cable was broken and lost in the former expedition. In the present machinery the shaft S of the paying-out drum P, Fig. 10, was prolonged on one side for the purpose of forming a coupling to the picking-up arrangement. It was considered advisable to make all this part of the machinery sufficiently strong to work with, and if necessary even to break, the large grapnel rope, which had a breaking strain of more than 30 tons. The shaft S was therefore made in its smallest place 7½ inches diameter. There were three points to be specially considered in the design: first, that the moving parts of the machine should be kept as light as possible, so that the momentum of the moving mass in paying out should be as small as possible, and should therefore strain the cable as little as possible, either in case of any sudden and accidental mishap, or when the ship was pitching; and this was of vital importance. Secondly, that the picking-up arrangement should be capable of being brought into action at a moment's notice. And thirdly, that the strength of the machine should be sufficient to cope with a rope having the uncommon breaking strain of 30 tons. These various requirements were admirably met by the arrangements adopted in accordance with the designs of Mr. Clifford, the engineer of the Telegraph Construction and Maintenance Works, who had also worked out the design of all the machinery employed in the expedition.

In order that the machinery for paying out might be as light as possible, the picking-up motion was coupled direct to the shaft S of the drum itself, as shown in Fig. 10; so that when the coupling was thrown out, the paying-out machine remained intact and as similar as possible to what would otherwise have been necessary if there had been no picking-up arrangement. This shaft and coupling had to be of the enormous strength necessary to bear a torsional strain of 30 tons, acting at a leverage of 2 ft. 8 ins. The shaft ends were squared, and a large wrought-iron coupling R capable of sliding along coupled the two shafts securely; and the application of this was simply the work of a moment. On the shaft H thus coupled to the drum shaft was fixed a large spur wheel of 7 ft. 11½ ins. diameter and 5 inches pitch: this pitch may at first appear excessive, but it is less than is in use for such exceptional strains. A train of gearing driving the pinion working into this wheel admitted of a ready alteration in speed and power, and was driven by a pair of trunk engines made by Messrs. Penn, having a nominal horse power of 80, but working in this case considerably below that power, as the condensing part of the engine was dispensed with and the steam supplied by the ship's boilers was only 20 lbs. pressure. The whole of the spur gear, which was of a very perfect construction, was supplied by Messrs. Jackson of Manchester, and was manufactured by their wheel-moulding machinery, which secured a remarkably true bearing surface on the teeth. The steam was conveyed to the engines by an 8 inch copper pipe of about 130 feet length; and as a considerable condensation was anticipated from such a great length of pipe, a separator and superheater were fitted close to the engines, so that they received their steam in about an ordinary condition.

In paying out the cable the portion in the after tank was first taken, in order to trim the ship, as she was considerably by the stern at starting; the fore tank was next emptied, and the middle tank left to the last, the ends of the cable from the several tanks having been spliced together originally in that order of connection. When each tank became nearly empty the ship was slowed down, and it was quite stopped for a short time whilst the paying out of the cable was transferred from one tank to another. This apparently rather delicate operation was effected on both occasions without the slightest difficulty. The whole of the cable in the three tanks was spliced up into one length before the paying out commenced; and the length between each tank was carefully laid in troughs of wet saw dust, so that it could be kept under electrical test; it was also from time to time thoroughly soaked with water. The total length of cable paid out was 1851 knots, and the time from shore to shore was 14 days, giving an average of 132 knots per day paid out, and an average rate of 5½ knots per hour for the cable. The total distance run was 1669 knots, making the average proportion of slack paid out 11 per cent.

The paying-out machinery was in principle identical with that used in the previous expedition of 1865, the only difference being that the frames of the machines were now made much stronger, as also the drums and their shafts, since they were constructed for picking up as well as paying out; many special arrangements were also made which fortunately were never called into requisition. Only one mishap of any importance occurred during the entire expedition, and that was when a large quantity of the cable fouled in the tank and came up all together on deck in the night of Wednesday 18th July, when about 700 knots had been laid. This entangled mass of cable was cleared after three hours' most exciting and anxious labour. The night was dark and raining, and a heavy summer gale was blowing; and only with the greatest care could the ship have been kept steady during so long a time. Evidently no appliances in the machinery could have been made to meet so extraordinary an occurrence. The ship was furnished with signal whistles, worked by air pressure constantly supplied from a steam engine, so that orders could be transmitted immediately and with the greatest precision to either the engine room or the bridges and steering deck; and probably the ultimate success of the expedition in no small degree depended on this arrangement.

During the whole time of the paying out the machinery was most carefully watched at all points. The drums were fitted with rotometers, showing the amount of cable which had been paid out; and this amount was carefully noted every fifteen minutes in the ship's log, and the speed of paying out and the speed of the ship were calculated so that a right amount of slack might be allowed. If the ship were travelling too fast, the speed was immediately reduced in the engine room; and if too much cable was being paid away, a small addition to the weights on the drum breaks usually remedied this defect speedily: in fact the whole working of the machinery showed that every difficulty which presented itself was fully overcome. Varying winds and currents and many other circumstances caused constant watching from moment to moment to be increasingly necessary. When at length the shores of Newfoundland loomed in the distance and the laying of the Atlantic cable was at last a success, and when the electrical tests which had been constantly trying the condition of the cable proved that it had in no way whatever been injured by the machinery during fourteen days' constant working, then could all on board realise the success of so much labour and thought, the result of so many years of constant application and experiment.

Picking-Up Machinery.—Probably no course made by a vessel across the Atlantic was ever more definitely known and accurately marked on the chart than that made in the year 1865 by the *Great Eastern* during the attempt to lay the Atlantic cable. When the cable parted in that year, many days were spent in the attempt to recover it; this time was however by no means wasted, as the results then obtained proved not only the possibility but the certainty that the cable could be found and raised from the bottom. It was a bold experiment—that of grappling for a cable at the depth of two knots—and was altogether without precedent: sailors, engineers, and theorists had repeatedly declared it absurd; but the result of the actual trial of grappling proved at all events that it was not absurd, and showed that perhaps even the ultimate recovery of the cable was not hopeless. The difficult task of placing the ship in such a position that it should drift across the line of cable was three times successfully accomplished in the attempts made in 1865 to raise the cable; three times the cable was hooked, and three times the swivels in the rope failed. For days the dragging was determinedly continued by Sir Samuel (then Mr.) Canning, the engineer in charge of the expedition, until every fathom of rope was exhausted, and there was then no hope left for that year. Sufficient however had been done to render it impossible that other attempts should not be made; and all who were present were only more thoroughly convinced than ever that a cable could be laid across the Atlantic, and most sincerely believed that the cable commenced in 1865 would yet be recovered and finished. It matters not here to relate the exertions which were necessary for persuading capitalists to proceed yet further in an undertaking considered by very many to be as impracticable as the search after the philosopher's stone; it is sufficient to know that the money was ultimately obtained, that the expedition was organised, and most important of all that it was successful. It is intended now to describe the means and the machinery by which this grand result was attained.

The cable of 1865 had been laid with about 15 per cent. of slack, and this percentage of slack was the great source of hope for the successful recovery of the cable. It was calculated that if the cable could be raised to the surface without hooking it at more than a single point, there would be a bight suspended in the water of 9¼ knots in length, when in 2 knots depth of water, as shown in the diagram, Fig. 5, Plate 2; and the horizontal distance J J would be 8 knots between the portions resting upon the ground, giving an excess of length of 15 per cent. in the suspended bight; and the results of the actual picking up proved this calculation to represent very closely the curve of the suspended cable. The size of the cable was 1⅛ inch diameter, and its weight 35¾ cwts. per knot in air, and 14 cwts. per knot when immersed in water; the total weight of a suspended length of 9¼ knots in water was therefore 6½ tons, but as the breaking strength of the cable was 7¾ tons, it would carry the weight of 11 knots of its own length in water before breaking. As however the possibility of its recovery in this manner in a single bight was generally considered to be out of the question, it was intended therefore to attempt raising it by degrees only. Three steamships were accordingly fitted with picking-up apparatus, the *Medway*, *Great Eastern*, and *Albany*, for the purpose of grappling for the cable simultaneously in three places: the *Medway* to grapple to the east and the *Albany* to the west of the *Great Eastern.*

The picking-up machinery was entirely new for this expedition, and was constructed for a much greater strain than the machinery employed in the attempts of the previous year. The Grapnel, shown in Fig. 15, Plate 7, was simply a very large ordinary boat grapnel made with five prongs instead of three; it stood about 4 feet high, was fitted with a swivel at the top, weighed about $2\frac{1}{4}$ cwts., and its prongs would carry a strain of about 8 or 9 tons without damage. Shackled to this was a 15 fathoms length of $1\frac{1}{8}$ inch chain, to which was fastened the grapnel rope. This rope was a most remarkable one, being $1\frac{7}{8}$ inch diameter, and consisting of seven strands, six strands round one; each strand again consisted of six smaller strands of hemp, in the centre of each of which was a wire about 1-10th inch diameter. The rope was repeatedly tested, and was never known to break with less than 30 tons strain. Its weight in air was about 5 tons per knot, and in water $3\frac{1}{4}$ tons.

At the bow of the ship were fitted four iron girders carrying three cast-iron sheaves about 3 ft. 9 ins. diameter; these sheaves were all clear of the ship, and over the centre one the grapnel rope was led on board, as shown at K in Fig. 2. The grapnel rope was led directly to the picking-up machine from the bow sheave, passing through a dynamometer so that the strain could be ascertained at all times. This dynamometer was similar to the one for the paying-out machinery described before, except that it was of a much heavier construction and loaded with a weight of 2142 lbs. The vertical travel of the dynamometer wheel was 5 feet, the horizontal length of deflected cable 30 feet, and the graduations of the scale ranged from 2 tons to 20 tons.

The Picking-Up Machine was very powerful, as it had to cope with a rope of 30 tons breaking strain, and if necessary to break it. It is shown in elevation and plan in Figs. 13 and 14, Plates 6 and 7. The two large drums B B, each 5 ft. 8 ins. diameter, were fixed on shafts parallel to each other at 11 feet distance apart from centre to centre. The grapnel rope A A was passed four times round these two in the manner shown in Fig. 13, passing away on the opposite side from where it entered on. The fleeting of the rope was effected by small disc rollers C C placed on shafts between the drums, four above and four below; and each part of the rope was fleeted after leaving one drum before it entered on the other, thus keeping every portion of the rope clear of the rest. The fleeting required much more care in this machine than in the one for paying out, as the shackles and swivels on the grapnel rope would capsize on and hold down the preceding coil of the rope on the drum, unless the four coils were all kept very wide apart.

As the strains to which it was expected the machine might probably be put were very great, it was thought advisable not to take the power through the shafts of the drums B B; and accordingly the drums had spur wheels D D fixed at each side, into which the pinions E E geared; and by this means no torsional strain whatever was put on the shafts of the drums. The strain of the grapnel rope was divided thus between four spur wheels, and the pitch of these was only 4 inches; although in the paying-out machine, where this division of strain could not be effected, the spur wheels were 5 inches pitch. Each of the drums had a break F fixed to it, and both the breaks were worked by one shaft G G with two screws on it, carried fore and aft along the machine over the breaks. All the strain of the breaks was carried by brackets H H on the sole plate, and in no way by the screw shaft G; and this is believed to be rather a novel application of the break strap, and may be worthy of remark.

The machine was driven by a pair of trunk engines, precisely duplicates of the pair employed in the paying-out machine; and these engines, together with the picking-up machine itself, were made by Messrs. Penn. There was also a system of gearing similar to that belonging to the paying-out machine, for admitting of a change of speed and power; the slowest speed, when the engines made 80 revolutions per minute, was about $\frac{3}{4}$ knot per hour, and the quickest about $1\frac{1}{2}$ knots per hour. The machine was supplied with a draw-off wheel I and jockey wheel J having an adjustable weight K, so as to keep the grapnel rope A well taut on the drums B; and a rotometer was added for measuring the length of grapnel rope overboard. When the picking up of the cable was in progress, the grapnel rope was delivered from the picking-up drums into the fore tank, which was at that time empty.

The process of grappling was as follows. The exact line of the cable having been marked by a couple of buoys put down by nautical observation, the ship was brought into a position about 3 or 4 knots north or south of this line, according to the direction of the wind and current, so that the ship might be drifted slowly across the line of the cable. The new cable of 1866 had been laid at a distance of about 30 knots southward of the line of the old cable, so as to avoid all risk of injury in the process of grappling for the old cable. In a depth of 1900 fathoms (nearly 2 knots), about 2200 fathoms length of grapnel rope with the chain and grapnel as before described was lowered with great care, taking about an hour or an hour and a half for the purpose. Whilst the grapnel was being lowered, accurate observations were continuously taken of the indications given by the dynamometer; and the grapnel striking the bottom was almost immediately indicated by a diminution of weight, as it and the chain weighed rather more than half a ton. About a couple of hundred fathoms of additional rope were then paid out, and the dynamometer from this time was most strictly watched; averages of the indications were taken every few minutes, and many hours frequently passed before there was the smallest change in these averages. It was interesting to observe how steadily these averages remained at about 8½ to 9½ tons, dependent upon the length of grapnel rope out, and the strength of the wind and current. An indicated rise of 5 cwts. was generally considered satisfactory evidence that the cable was once more hooked, and this seldom proved wrong; no attempt however was made to haul in the rope until the strain rose 2 tons above the average. As soon as a strain of 10½ to 12 tons was observed, the ship was brought up by her engines to ease the strain, and the operation of picking up commenced; the strain then generally rose to about 14 or 15 tons, and continued at this amount until the bight of the cable was raised off the ground, after which time it gradually lessened. The attempt was once made to raise this bight direct to the surface without assistance from the other ships, and it proved successful, the cable coming a few feet above the water with a strain of about 6½ tons. There was however a heavy swell on at the time, and the pitching of the ship broke the cable through.

After many ineffectual attempts, the cable was at length successfully raised in the following manner. It was hooked by the *Great Eastern*, and the bight being raised about 900 fathoms from the bottom was buoyed there, as shown at B in Fig. 6, Plate 2: the buoy attached was of the largest size, weighing 3¼ tons, and capable of supporting a weight of 13 tons. The *Great Eastern* then again grappled for the cable about 3 or 4 knots westward at S, and again found it; the *Medway* found it at the same time at M, about 2 knots westward of the *Great Eastern*. The *Great Eastern* then commenced hauling in, signalling to the *Medway* to do the same, and to break it if she could not bring the bight to the surface; this she accordingly did, the cable breaking about 200 fathoms below the surface. The *Great Eastern* in this manner had a loose end of about 2 knots to the westward, and had immediately a much reduced strain to contend with. Ultimately the end was successfully brought on board, the electrical circuit to Valentia was once more established from the ship, and the movement of the small speck of light on the galvanometer scale by the current received from Ireland indicated the success of the undertaking. A shout of joy spread through the ship, the guns bellowed out the welcome news to the other ships; and the anxiety of nineteen days' continuous trial, which had culminated in an intensity that was most significantly betokened by the oppressive silence whilst the end of the recovered cable was being tested, now gave way to universal cheering and excitement.

The recovered end was speedily spliced on to the remaining portion of cable coiled in the tanks on board; and the ship was soon slowly proceeding onwards again with her head to the west. The paying-out machinery was from that moment all that possessed any interest; the picking-up dynamometer, which had been so constantly watched, was left deserted; and the hum of wheels, jockeys, and drums, was the sound most welcome to all on board. This fortunately continued without interruption until the ship's arrival the second time at Heart's Content, Newfoundland, thus completing the laying of the remaining 680 knots required to finish the original cable of 1865.

Specimens were exhibited of the new cable of 1866, and of the recovered cable of the previous year with the grapnel rope by which it was picked up, together with the original charts of the laying and picking up, which were lent for the occasion by the kindness of Captain Sir James Anderson.

Mr. C. W. **Siemens** considered they were much indebted for the very interesting and valuable particulars given in the paper respecting machinery which had been successful in achieving such an important work as the laying of the Atlantic telegraph cable, and which appeared in all its details to have been most carefully arranged. In the previous expedition of 1865 there was no doubt that a great mistake had been made in having the picking-up machinery separated by a distance of more than 600 feet from the paying-out machinery, the two being at opposite ends of the great ship; and this he considered had caused the loss of the cable in that attempt. There was no occasion however for the use of separate machines for paying out and picking up, and machinery had previously been designed by himself for serving the double purpose of paying out and picking up (shown in Figs. 16 to 23, Plates 8 to 10), which was made by Messrs. Easton and Amos and fitted on board the *Dix Decembre*, a French telegraph ship that had done a great deal of actual service in laying and picking up telegraph cables in the Mediterranean. The engine A, Figs. 17 and 19, was placed on deck near the paying-out gear B, at the stern of the vessel; and the machinery was driven by the strap C tightened by the hand lever D, so that it could be thrown out of gear at any time. By this means he had frequently reversed the action of the machinery from paying out to picking up within only a minute or two, which he considered was a point of special advantage in such operations, by admitting of readily hauling in the cable for examination or repairs; for if any accident happened to the cable in paying out, such as any deficiency occurring in the electrical tests, it was most essential that there should be facilities for picking up the cable immediately and examining the injured place. In picking up by this arrangement, the vessel had of course to be drawn backwards by the strain upon the cable in being slowly hauled in; and in the case of a head wind this strain was diminished by working the ship's engines slowly in the backward direction. The *Dix Decembre* had been largely employed in picking up the Port Vendre and Minorca cable and other old Mediterranean cables, hauling the cable in at the stern, with most satisfactory results. If on the contrary in order to haul in the cable it had to be taken round along the whole side of the vessel from the stern to the bows, there was very great risk of injuring the cable, or of losing it altogether as occurred in 1865, because during the whole time of making the change the vessel was in effect riding at anchor upon the cable. He could only suppose that that mode of procedure arose from the old notion of sailors that the bows of a ship were the proper place for taking in a cable, because the anchor rope was always taken in at that end.

In paying out a cable, the dynamometer for showing continuously the strain under which the cable ran out was a most essential instrument, and in the arrangement described in the paper a weighted pulley working between guides rested upon the cable midway between two carrying wheels over which the cable passed. This construction however he thought was not so free in its action as the arrangement shown in Fig. 20, which he had adopted and had found completely successful, having the weighted pulley E carried at the extremity of a lever F, so that it rested freely upon the cable G; the lever was loaded either by a weight H, or by springs, the latter being preferable on account of their greater steadiness of action. A scale attached to the lever showed at all times the amount of strain upon the cable.

In place of loading the friction breaks of the paying-out drum by means of dead weights, as had previously been done, with the addition on the *Great Eastern* of water cylinders to prevent undue oscillation of the weights, as described in the paper, he had adopted a plan of loading the breaks which he thought had an advantage in delicacy and certainty of action, by the use of a hydraulic cylinder K, Figs. 20 and 21, loaded by a constant pressure of water upon the piston, according to a suggestion originally made by Professor Rankine and embodied in the design of the machinery on the *Dix Decembre.* The supply of water to the cylinder K was maintained by the pump L, Fig. 20, driven constantly by a strap from the shaft of the paying-out drum B; and the water being delivered along the pipe M communicated by the four-way cock I with the top of the break cylinder K, and passed up the rising pipe N to the regulating valve J in the tank P, shown to a larger scale in Fig. 22. The cylindrical casing of the valve J had four V shaped orifices, through which the water entering from the pipe N escaped continuously into the external tank P, the rate of escape being regulated by the position of the plunger J forming a piston valve, which was loaded by a spring-balance Q, like an ordinary safety valve. By this means a constant pressure was maintained upon the top of the piston in the break cylinder K, and the load upon the break R in paying out was thus readily adjusted by screwing the spring-balance Q to the desired pressure; while at the same time the load upon the break could never exceed the maximum to which the spring-balance was adjusted. The bottom of the break cylinder K communicated by the four-way cock I and the exhaust pipe S with the tank P, but outside the regulating valve J, so that the loading pressure was not conveyed to the underside of the piston in the break cylinder; and in order to allow of a slight amount of yielding in the hydraulic break, and to give it a sort of elastic action, the four-way cock I was itself made with a small hole through the plug, as shown to a larger scale in Fig. 23, through which a constant small leakage took place from the pressure side into the exhaust pipe. The break R was rendered self-relieving by the lever T, Fig. 21, in the same manner as described in the paper. There were two of the friction breaks R R, Fig. 17, one on each side of the paying-out drum B; and the two rising pipes N N from the break cylinders K K both entered under the same regulating valve J, Fig. 22, whereby the load was maintained always exactly equal upon both breaks. The water escaping from under the valve J into the tank P was delivered by a pipe U upon the top of each of the breaks for the purpose of lubricating them. When driving the drum B in the contrary direction, for picking up the cable, it was only necessary to reverse the four-way cock I; and the pressure then acting below the piston in the hydraulic cylinder K slacked the break strap off the break, while at the same time the lubrication by the waste water from the tank P continued undiminished, so that the drum B revolved freely without the action of the breaks.

In the laying of the Atlantic cable he was glad to see that water-tight tanks had been adopted for containing the cable on board the *Great Eastern*, as that was a measure which he had recommended for many years, because it preserved the cable from injury and allowed of a system of continuous tests during the whole time of the laying. In addition to the water-tight tank containing the cable in flakes or layers, an arrangement employed for light cables in the *Dix Decembre* was to carry the coil of cable upon a circular turntable revolving on a set of live rollers in the water tank, as shown in Fig. 18.

With regard to the grappling for the recovery of the cable of 1865, one fortunate circumstance connected with the Atlantic ocean was that its bottom appeared to be perfectly smooth and homogeneous. In the Mediterranean sea however, where he had grappled a cable at a depth nearly but not quite equal to that of the Atlantic, the circumstances had been much less favourable in those respects; and the dynamometer was therefore by no means so steady, but was liable to fly up suddenly to perhaps 15 cwts. and drop down again to 4 or 5 cwts., so that it was impossible to decide with such accuracy as in the Atlantic whether the cable was taken hold of by the grapnel or not. The reason no doubt was that the Mediterranean had a rocky bottom, full of coral formations in moderate depths, and rocky even at its greatest depths; whereas the bottom of the Atlantic appeared to be almost perfectly smooth. Another circumstance highly in favour of the Atlantic cable was that there seemed to be no animal life at the bottom of the ocean; whereas in the Mediterranean, if such a cable covered partially with hemp were put down to the bottom, it would be utterly destroyed in a few months by animals breeding upon the cable and eating up the hemp, leaving the wires unprotected and a mere burden upon the tender core. This had been the case with the early Candia and Chios cable and with the Toulon and Algiers cable laid in 1859, both of which had become entirely useless after being down, the former only six months, and the latter only about eight months. On the contrary the specimen now exhibited of the recovered Atlantic cable of 1865, which had been down at the bottom of the ocean for twelve months, was evidently as perfect as at the time that it was laid, although its construction was the same as that of the Toulon and Algiers cable. On all accounts therefore there seemed every reason to hope that the Atlantic cable now laid would prove a durable one.

Mr. W. FAIRBAIRN remarked that the laying of a cable across the Atlantic was one of the most important undertakings in ocean telegraphy; and having had an opportunity of inspecting the whole of the machinery a few days before the *Great Eastern* sailed on the last expedition, he considered it was most carefully constructed and arranged, so as to preclude any liability of mishap during the laying of the cable. The success that had attended the operation of laying the cable was mainly due in the first instance he thought to the use of the *Great Eastern* for conveying the cable, whereby the entire cable was contained in the hold of one vessel by means of the three tanks; so that by connecting these three lengths together in the vessel the entire cable was tested continuously during the whole process of laying it from Ireland to Newfoundland, and by this means any failure in the electric currents would have been instantly detected. The operation of paying out the cable had been admirably performed, as described in the paper, and the success with which it had been accomplished showed how well the machinery had been adapted for the purpose. Having made the experiments upon the tensile strength of the cable and also of the grapnel rope, he had found the results most creditable to the manufacture of both. One difference between the previous cable of 1865 and the new one of 1866 was that the former was coated with pitch, while the latter was left clean;

and it had been found that in going over the pulleys of the paying-out machinery the grooves became so glutinous and sticky with the pitched cable that there was great difficulty in keeping them sufficiently clean; the new cable however without the pitch was paid out with the greatest possible ease, and this he thought contributed largely to the success of the laying. With regard to the destruction of the hemp covering by marine animals, even supposing the whole of the hemp were eaten off by them, the cable he believed would continue in complete working order, provided they did not attack the gutta-percha which formed the insulator. The outer covering of hemp appeared to him of very little importance or value after the laying of the cable had been accomplished, and so long as the insulator remained complete, he thought it would not be of fatal consequence if the whole of the outer covering were decomposed or eaten off. There appeared every reason to believe that the two cables now laid across the Atlantic, remaining perfectly quiescent at the bottom of the ocean, at so great a depth below the surface and under such a heavy pressure of water, might continue in perfect working order for a great number of years.

Mr. J. T. **Wright** observed that he had been out to the Mediterranean a few months previously and had had an opportunity of examining a portion of one of the cables that had been raised for repairs; and it was found that, though the marine animals had destroyed the hemp, the cable remained electrically perfect and efficient wherever not damaged by excessive strain upon the core.

Mr. C. W. **Siemens** said he had seen the hemp covering of a cable entirely eaten away, and even the gutta-percha indented about 1-16th or 1-8th inch, but beyond that point the action of the marine animals did not appear to go. With regard however to the safety of the cable when deprived of its hemp covering, although it might continue efficient if lying upon a perfectly smooth bottom and with the tensile strain perfectly equalised throughout its length, yet that would certainly not be the case in the Mediterranean, where he was satisfied that as soon as the cable had ever worn weak at any point it would break, because the bottom of the sea was so uneven that the cable hung unsupported in a great many places. He had seen pieces of Mediterranean and Red Sea cables which had evidently given way at points of suspension by the rusting of the iron wires; and wherever the cable had parted, the core had been elongated several inches, and had shown electrical faults. Wherever the bottom was not perfectly smooth, the strains produced by the suspended portions of the cable must ultimately lead to fracture, if the iron wires became laid open to the action of rusting. So long as a cable retained its full strength, it was not indeed necessary that it should be perfectly supported throughout its entire length; but unless it were proved that the bottom of the Atlantic was so perfectly even that no portion of the cable would be in suspension, the continuance of the cable in working order must be dependent he considered upon the durability of the hemp covering protecting the iron wires from corrosion, which in the absence of marine animals might be for many years.

In addition to preserving the iron wires from rust, it must be borne in mind that the durability of the hemp covering was also essential to the strength of the cable, in consequence of the hemp acting as a packing to keep the wires at the proper distance apart. If the hemp were eaten away, the wires would be left like a loose cage round the core, and the latter would stretch and become faulty in consequence.

Mr. W. **Fairbairn** had no doubt that in situations where the bottom of the sea was irregular, as in the Mediterranean and other volcanic districts, sharp points of rock would be met with where a cable would be carried by suspension in the manner that had been described; and he suggested that in such cases, where there was a liability of the hemp becoming abraded or eaten away by marine animals, an exterior covering of wires should be employed without hemp, so as to assist in preserving the full strength of the cable unimpaired by time. In the Atlantic however the apparently level character of the bottom led to the conclusion that no such difficulties would arise in connection with that cable; and with regard to marine animals, although they had been proved to exist in other seas at a depth of even 2 or 2½ knots, it did not appear clear that any danger was to be apprehended at so great a depth at the bottom of the Atlantic.

There seemed every reason therefore to expect that the Atlantic cable now laid would be as perfect after twenty or thirty years' work as at the present time.

Mr. E. A. **Cowper** thought there was no question that wherever marine animals existed they would eat away the hemp covering of such a cable as the Atlantic and would even attack the gutta-percha of the core; and as the sea water would exercise a corrosive action upon the iron wires as soon as the hemp covering was gone, it would become a mere question of time in such cases how long the cable would last. It was clear therefore that in such a sea as the Mediterranean, where the bottom was so irregular, and where animal life was known to exist down to the very bottom, it would be useless to attempt laying down a cable of the construction adopted for the Atlantic; and for such cases he considered the construction of cable designed and laid down by Mr. Siemens was well adapted, having the layer of hemp placed inside the cable, surrounding the core, while the external covering was formed of a sheathing of copper strips wound spirally on, whereby the cable was completely protected from the action of the water or the attacks of marine animals.

In reference to the description given in the paper of the grappling and raising of the previous cable of 1865, as shown in Fig. 6, it appeared that, after the cable had been first grappled and buoyed up at B to a height of about 900 fathoms from the bottom, the *Great Eastern* grappled it again further westward and raised it to the surface at S, where the splice was made, and the paying out then commenced of the additional length for completing the cable to Newfoundland; and he enquired whether the state of the cable had been examined at the bight B where it had been buoyed, and whether it exhibited any signs of injury from the grapnel pulling at it in that part.

Mr. F. G. **Wynne** said that he had been on board the *Great Eastern* during the paying out of the new cable, and afterwards on board the *Albany* which grappled in concert with the two other ships. After the splice had been made at the point S where the cable had been raised to the surface, the paying out of the additional length for completing the cable had been proceeded with at once, and no examination had been made of the bight B where the cable had been grappled and buoyed, because the cable was proved to be electrically perfect; and there was no fear of injury having been occasioned to the outer covering, because the loose end brought up by the *Albany* showed only a very slight indentation where it had been hooked by the grapnel. The nautical observations taken in 1865 of the exact position of the broken end, though of great use in the first grappling for the cable in 1866, were not used in the final grappling, which was done 90 knots eastward of the first grappling; this was in order to avoid a deep depression in the bottom of the ocean, and also because the *Albany* had brought up a 2½ knots length of cable to the eastward of the place where the *Great Eastern* had first grappled and raised the cable to the surface; and the examination of this piece proved that, even if the cable had been successfully raised where first grappled, there would have been no communication with Ireland. The westward end of the length brought up by the *Albany* was found to have the copper conductor corroded to a length of about ¼ inch inwards from the end; and as this corrosion was no doubt due to the testing from Valentia, it showed that the cable must have been broken at that place in the previous year's operations, and the other end had no doubt been broken in the grappling of 1866.

In the paying out of the cable from the *Great Eastern* and the dragging with the grapnel, the successful working of the dynamometers was mainly due he thought to the steadiness of the ship itself; but even there the movement was so great when grappling in bad weather that it was often necessary to take averages of ten or twelve successive oscillations, in order to determine accurately enough the strain upon the grapnel rope. In the *Medway* and *Albany* however, on account of the smaller size of the vessels themselves, the dynamometers used to jerk up frequently through the whole range of the index from bottom to top, with such violence as to force the water out of the top of the water cylinder and render it useless, so that it had to be replenished with water at frequent intervals, sometimes every ten minutes.

In the new cable now laid across the Atlantic, the hemp covering was not left plain throughout the entire length, but there were several considerable lengths of it that were tarred. During the paying out of the untarred portion of the cable, temporary accidents in the tanks containing the cable were not unfrequent, owing he believed to projecting ends of wire catching in loose portions of the hemp covering of the adjacent coil; but in consequence of the care and promptitude of the men in instantly catching the lifted coil, only the one serious accident occurred that was mentioned in the paper. Loose ends of wire were also frequently detected by the scratching sound they made in running through the paying-out machinery. No such accident however that he knew of occurred with the tarred portion of the cable, in which the tar seemed to close down completely the loose bights of hemp in the cable.

With regard to the question of animal life at the bottom of the Atlantic, he had seen three long conical shells, two of which were perfect, brought up from a depth of 2000 fathoms, having been entangled in the grapnel rope of the *Albany*; they were all apparently of the same species, but he believed there was nothing alive in them. It appeared that the grapnel rope must have passed through a considerable number of them, because the three brought up were within a few feet of one another on the rope. Specimens of the worm on which the codfish feeds were also met with at considerable depths on the grapnel rope, but these might have been caught upon the rope while hauling it up.

The PRESIDENT remarked that, having had to construct the picking-up machinery on the *Great Eastern* and the engines for driving it, which were non-condensing, he had considered it important to make provision for extra security against the possibility of any undue strain ever coming upon the cable from any accidental increase of steam pressure in the engines, as they were of rather large power for the work they had to do. For this purpose he had added a very large safety valve upon the steam pipe, between the throttle-valve and the slide-valve chest, and this safety valve was loaded by a spring to the limit of pressure of steam intended to be supplied to the engines, 20 lbs. per square inch; a very long spiral spring was used, in order to obtain a great amount of elasticity, so that if the boiler pressure ever rose beyond the limit of 20 lbs., the excess of pressure would not be able to reach the pistons of the engines, but would be carried off by this large safety valve.

He proposed a vote of thanks to Mr. Elliot for the paper, which was passed.

The following paper was then read:—

ON THE COMPOSITION AND DURABILITY OF LOCOMOTIVE BOILER TUBES IN REFERENCE TO COAL-BURNING.

BY MR. GEORGE A. EVERITT, OF BIRMINGHAM.

The question of Coal-burning in locomotive engines and its consequent action on the Copper Fireboxes and Brass Tubes has drawn attention to the importance of ascertaining the best alloy of brass for the tubes, and also to the necessity of overcoming the difficulties often experienced from the copper plates of the fireboxes being of hard or brittle quality; and the opinion has been extensively held that the duration of the brass tubes and copper plates has been lessened since the general adoption of coal-burning in locomotives.

Previous to the year 1852 three qualities of metal were recognised in copper smelting: namely, tile copper, tough cake, and best selected copper. Of these the tile copper was the lowest quality, and there was a difference in cost of £2 per ton between each quality. The best selected copper is produced by stripping or skimming off the upper surface of the melted metal in the smelting process, this portion being the purest quality of metal; the upper portion of the remaining metal formed the second quality or tough cake copper; while the tile copper was the residue at the bottom of the melting pot, containing the largest proportion of impurities. In 1852 the description called tile copper was discontinued, and the other two sorts only were made, namely tough cake, and best selected copper, with a difference in cost of £3 per ton. This change however did not prove beneficial in respect to the durability of copper plates and sheathing made from the new description of tough cake copper, which was not of such good quality as previously; for owing to the very great demand for best selected copper for the manufacture of Muntz's metal for sheathing and of brass tubes for locomotives &c.,

the stripping or skimming process in the smelting was now carried too far, the cake copper being seriously robbed by the greatly increased proportion of metal skimmed off to form the best selected copper, whereby the remainder was left inferior in quality to what it should be, and little if at all better than the tile copper of former years, while the best selected copper itself was also injured in quality by containing too great an admixture of impurities.

As early as 1858 it was found at Chatham dockyard that the copper sheathing of ships' bottoms, which is made from cake copper, did not last so long as before the above change; and copper sheathing which had been in use only two years was found to have lost as much as 14 per cent. of its weight; whereas only ¼ per cent. of the weight had been lost after eighteen years' wear of copper sheathing made in 1825, at which time but little best selected copper was made, the stripping or skimming process not having then been introduced to any considerable extent. At the present time the average duration of the copper sheathing on ships' bottoms is reduced to only three or four years, instead of from twenty to twenty-five years as formerly, owing solely it is believed to the extent to which the stripping process is now carried. The same explanation probably accounts also for the complaints which are frequently made that the copper firebox plates for locomotives are found inferior in quality to those obtained in former years.

The great and increasing demand for best selected copper undoubtedly caused a large quantity to be supplied under that designation which was not even so good as the tough cake of former years. Attention was again drawn to the subject at Chatham dockyard on the occasion of a ship which had lain some time in the harbour being suddenly ordered for sea; the brass tubes in the boilers, which were new, were then found to be leaky, and had to be taken out and the boilers re-tubed before the ship could proceed to sea. The cause of this and other similar failures was considered to be that the copper used in the manufacture of the tubes must have been of inferior quality, and not best selected as it ought to have been.

The following method of testing was consequently adopted by the Admiralty in 1865 for ensuring the use of the proper quality of copper in brass boiler tubes for marine purposes. Portions of several of the tubes are melted in a crucible, and zinc is added until the compound contains as nearly as possible 62 per cent. of copper and 38 per cent. of zinc, which is a composition that can be rolled hot and appears to give the maximum of tensile strength. The metal is then cast into an ingot, and after being brought to a low red heat in an annealing furnace is rolled out into a plate ¼ inch thick, from which strips are cut 1 inch wide. If the proper quality of copper has been used, these strips then stand a tensile strain of at least 6 tons each, equal to 24 tons per square inch; and the fracture when broken across presents a silky appearance in texture, which cannot be obtained if common tough cake copper has been used, or even ordinary selected copper, as none but the best selected copper gives this appearance to the fracture. As the quantity of copper contained in brass tubes is much in excess of the composition here fixed for the purpose of testing, it may appear strange to add zinc for reducing the proportion of copper; but the reason is that the richer alloys are so ductile that they elongate considerably under a tensile strain, and will not stand anything like the breaking strain of 24 tons per square inch, nor will the test composition containing the 38 per cent. of zinc stand the test, if annealed previous to testing. Another advantage in adopting the lower percentage of 62 per cent. of copper is that the appearance of the fracture of the low alloy gives a better test of the quality of the copper than a richer composition would afford.

From a number of experiments upon the tensile strength of alloys containing the above proportions of 62 per cent. of copper and 38 per cent. of zinc, it was found by the writer that only a few of the makes of best selected copper taken indiscriminately came up to the required strength; and a quality that would stand the test could only be ensured by an extra price for the copper. At the present time however some of the copper smelters have accepted this test, and produce a quality of best selected copper which is quite up to the mark. Great benefit has certainly been derived from the government researches in this matter, which have undoubtedly caused an improvement in the quality of best selected copper; and the standard test above described is now invariably adopted by the writer for all best selected copper used in the manufacture of brass tubes for boilers.

The brass tubes in most general use at the present time for locomotive and marine boilers are known as solid-drawn tubes, consisting of two parts of copper to one part of zinc, which proportion becomes a little changed in the process of manufacture, owing to the volatility of the zinc when melted: and on analysis the writer has found the composition of the metal to be copper 69 or 68 per cent. and zinc 31 or 32 per cent. The question arises however whether this is the best alloy for the purpose, and whether the addition of more copper would not increase the durability of the tubes, especially in resisting the action of sulphur in coal-burning engines with bad coal; and the writer was first led to consider this question by finding some years ago that the practice on all the French railways was to adopt a standard composition containing at least 70 per cent. of copper, which was adhered to for all locomotive tubes. In this country the same conclusion has been arrived at on the North Eastern Railway, where it has been found by Mr. Fletcher after more than twenty years' experience with tubes of this composition that they are more durable than those containing a smaller proportion of copper; and consequently all the tubes for that railway are now required to contain 70 per cent. of best selected copper and 30 per cent. of best Silesian spelter. The actual results of working on that line, where the water is unusually bad, have been that 15 sets of tubes containing 70 per cent. of copper or upwards lasted an average of 87,808 miles each; while the average of 54 sets containing a lower proportion of copper was 81,665 miles. It is difficult however to arrive at any reliable statistical information respecting the duration of tubes, as it is materially affected by the quality of the water used in the boilers, and also by the quality of the coal as regards its freedom from sulphur; their average duration throughout the railways of this country may be taken at from 100,000 to 150,000 miles.

The proportion of 70 per cent. of copper is considered by the writer so great an improvement that it has been adopted as the composition of the locomotive tubes of his own manufacture; and this opinion is confirmed by the circumstance that the alloys of brass used for other purposes, such as to resist the action of sulphur and acids, are always made with this or even a higher percentage of copper. Hitherto the composition of locomotive tubes has been very various, the percentage of copper extending down to the proportion in the composition known as Muntz's metal, which is ductile when worked hot and contains 60 per cent. of copper and 40 per cent. of zinc; and one advantage which will attend the adoption of a standard percentage of copper in boiler tubes will be that old tubes when taken out of the boilers will have a certain definite value exactly in proportion to their weight.

The question of the best thickness of metal for the tubes is one of much importance, and one on which great diversity of practice at present exists upon the different railways; but with the increased percentage of copper in the composition it may safely be assumed that greater ductility will be obtained, and that some reduction in thickness of tubes may be made without diminishing their durability. The thicknesses of tubes range from as much as 9 and 13 wire-gauge (·150 and ·095 inch) at the thick and thin ends respectively, down to as little as 13 and 15 wire-gauge (·095 and ·070 inch); the most general practice of the leading English lines being about 10 and 13 wire-gauge (·135 and ·095 inch). The thickest tubes, of 9 and 13 wire-gauge (·150 and ·095 inch), have only been used regularly on one or two railways; and a serious difficulty having been experienced in keeping these thick tubes tight with very long fireboxes, a trial has been made at the writer's suggestion of the thin tubes of 13 and 15 wire-gauge for that purpose, whereby the previous difficulty of keeping the tubes tight has been obviated. The relative durability of the thinner tubes has not yet been proved; but an important saving in first cost is effected, the thick tubes having weighed 26 lbs. each for 11 feet length, while the thin tubes weigh only 21 lbs. each, effecting a saving on a set of 150 tubes of

750 lbs. weight, amounting to £29 in cost. Very good results have been obtained on one large railway with these thin tubes of 13 and 15 wire-gauge and $1\frac{9}{16}$ inch external diameter, in locomotives burning coal exclusively.

The greater rigidity of the thick tubes may have caused the difficulty previously mentioned of keeping them tight, the thick tubes not yielding so readily as the thinner ones to the inevitable difference in expansion of the brass tubes and iron boiler-shell. That this difference in expansion is a point of importance is seen from the circumstance that in a length of 11 feet the expansion of iron at 350° Fahr., the temperature of 120 lbs. steam, is $\frac{1}{4}$ inch, but that of brass is $\frac{3}{8}$ inch, giving a difference of 1-8th inch, which has unavoidably to be allowed for either by compression of the metal or by lateral springing of the tubes. On many railways the tubes are now annealed throughout, and the same practice has also been adopted to some extent by the Admiralty for marine boiler tubes; which tends to show that softness combined with great ductility is the desideratum needed.

On foreign railways it may be remarked that a different construction of tubes has been extensively tried, namely wrought-iron tubes with copper ends brazed on at the firebox end. The copper ends are bevilled to a feather edge on the inside and the tube ends in a similar manner on the outside, and the two are then brazed together. The object of this construction is to give the ductility of copper at the end where the tubes are flanged over the firebox tube-plate, and thus to overcome the difficulty of leakage, which has always been the great objection to iron tubes in locomotives. Although by this means an economy is effected in first cost by the use of iron tubes, in practice the saving is not so apparent; and on many foreign railways where such tubes have been tried, brass tubes are now being substituted for them. On one railway in Russia tubes of copper alone are used, but the fuel employed in that case is wood; and in the peat-burning locomotives on the Grand Trunk Railway of Canada brass tubes are now being substituted for the iron tubes previously tried.

Brass tubes are found to suffer serious damage from long exposure to damp, and to become hard or brittle, losing their ductility. This arises possibly from the circumstance that the injurious action known to be produced upon brass by the sulphurous acid gas present in the atmosphere of towns is greatly dependent upon the presence of moisture in the atmosphere; and at the writer's suggestion the stores for brass locomotive tubes have in some cases been heated and enclosed, with advantageous results in preserving the tubes from damage.

Mr. Everitt exhibited a number of specimens of the testing of brass, and showed the hydraulic press in action by which the testing of the samples was effected. He explained that the practice at his own works in testing best selected copper was to mix 6 lbs. of the copper with 4 lbs. of best Silesian spelter, whereby the proportions in the resultant alloy became about 62 per cent. copper and 38 per cent. zinc. This was then rolled down into a plate 4 inches wide and of exactly $\frac{1}{4}$ inch thickness, which was cut into two portions, one being left hard for testing the tensile strength, and the other being annealed for bending. The latter was bent cold, and was required to stand being bent over completely double and hammered close, without any signs of cracking, as shown in the specimens exhibited, all of which had undergone this treatment without failing. The hard portion of the test plate was cut down in the centre of its length to a width of exactly $\frac{1}{2}$ inch, so as to present a section of $\frac{1}{4} \times \frac{1}{2}$ inch or 1-8th square inch to be ruptured by tension; this was then fixed in the hydraulic press, and the pressure was increased till the fracture was effected. With 62 per cent. of copper it was found that the specimens required a tensile strain of 13,000 lbs. to break them, equivalent to about 46 tons per square inch upon the initial section; but when the proportion of copper was increased to 70 per cent., the breaking strain became reduced by the greater ductility of the metal to 10,000 lbs., or about 36 tons per square inch on the initial section. This confirmed the plan of testing prescribed by the Admiralty, in which zinc was required to be added to the alloy until the proportion of copper was reduced to 62 per cent. The specimens exhibited of the test pieces all showed the silky appearance of fracture, which indicated that the quality of the copper was of the required excellence. He showed also specimens of locomotive boiler tubes containing 70 per cent. of copper, of which the ends after being annealed had been flanged over when cold, for the purpose of testing the ductility of the metal; in one instance, the tube being $2\frac{1}{8}$ inches outside diameter, the flange had been spread out at right angles to the tube to $3\frac{5}{8}$ inches diameter; and in another tube of the same diameter the flange had been bent completely back upon the tube; in neither case were there any signs of cracking on the surface of the metal or at the edge of the flange.

Mr. E. A. Cowper considered they were much indebted for the description given in the paper of the actual proportions of copper and zinc employed in the manufacture of brass tubes; and the practical experiments that had been described and exhibited appeared conclusive as to the value of the increased percentage of copper in boiler tubes, and the importance of testing the quality of the copper. It was clear that some definite proportion of copper and zinc must be better than others for boiler tubes; and it was very desirable therefore that the best proportion should be adhered to in all cases, instead of tubes being made as hitherto of a variety of different compositions. In the case of gunmetal for bearings &c. it was usually the practice to specify beforehand the exact proportions of metal to be employed; and it would be desirable for the same plan to be carried out in respect to the composition of boiler tubes. In the investigation made by government respecting the quality of the copper employed for sheathing of ships and for marine boiler tubes, he understood it had been stated that the decline in the quality of best selected copper dated from the introduction of a great many sorts of foreign copper ore, particularly those from Australia and Peru, containing different sorts of impurities; and that it was no longer possible to get best selected copper made from Cornish ores alone, which were more free from impurities than Australian ores.

The presence however of a small percentage of phosphorus in copper proved an advantage he believed, by increasing the ductility of the metal, though damaging it for electrical purposes.

Mr. Everitt thought it was not the quality of the best selected copper so much as the quality of the residue which had deteriorated in comparison with former years; and although by mixing with the Cornish ores the Australian and Chilian, containing a great variety of impurities, a less pure quality of metal was produced than had previously been obtained from the less rich but purer Cornish ores, there was no doubt that it was possible at the present time to make as good a quality of best selected copper as had ever been made, or even better. But the real difficulty was that so much best selected copper was wanted that the metal was stripped to such an extent in the melting process as to cause the quality to be very much deteriorated, both of the best selected copper itself, and especially of the inferior description left behind, or cake copper, which was the quality employed for the copper sheathing of ships.

Mr. S. Crosby remarked that at the commencement of the manufacture of the late Mr. Green's solid-drawn tubes in 1841 the only copper used was that obtained from Messrs. Sims Willyams and Co., which was the best that could be procured at the time and considerably more expensive than the other qualities. But of late years some very inferior material had been made as best selected copper, which had consequently produced a serious difference in the quality of the tubes manufactured from it, although no alteration had been made in the proportions originally adopted by Mr. Green of 2 parts copper to 1 part zinc. The extent to which this deterioration was carried led at length to the investigation of the subject by government, originating in the discovery of the circumstance mentioned in the paper, that the tubes in a steamer which had lain by for a long time had become rotten: this was a liability to which all brass tubes were exposed, when kept in a damp situation, and particularly when also made of an inferior quality or lower proportion of copper. Until that investigation the difference in the durability of boiler tubes had never been ascribed by the users of the tubes to the difference in the quality of the copper employed, but solely to the proportionate composition of the brass. The result of the experiments then made at Woolwich had been the establishment of the system of testing described in the paper for ascertaining the quality of the best selected copper; and also the adoption of the same proportion of copper and zinc for marine boiler tubes, namely 2 to 1, that had been throughout used by Mr. Green. With this proportion, if the quality of the copper was sufficiently good to stand the prescribed test, and if it was also mixed with the best Silesian spelter, the tubes manufactured from the alloy would certainly prove thoroughly satisfactory as far as marine boilers were concerned. In regard to locomotive boilers, although the same proportion was as a rule satisfactory in this case also, there were unquestionably some railways upon which a considerably higher proportion than 67 per cent. of copper was necessary in the tubes, even with the very best copper that could be obtained; but he could not say whether this arose from any excess of sulphur in the coal burnt in those engines, or from some other cause not yet clearly ascertained.

With respect to the thickness of metal in locomotive boiler tubes, the original dimensions adopted by Mr. Green, by whom the plan was introduced of making the tubes taper in thickness, had been No. 12 wire-gauge (·110 inch) at one end, tapering to No. 14 (·085 inch) at the other. Previous to that time all locomotive tubes had been parallel in thickness throughout the entire length, the thickness being No. 14 (·085 inch) or thicker. Subsequently on the Liverpool and Manchester Railway a thickness tapering from Nos. 10 to 13 (·135 to ·095 inch) had been adopted by Mr. Dewrance, after going carefully into the matter; and he believed this section had continued to the present time to be the one in general use upon most railways. On the Bristol and Exeter line Nos. 9 to 13 (·150 to ·095 inch) were the dimensions used until recently; but in that district also the belief had lately been gaining ground that thinner tubes would answer the purpose equally well, particularly where the coal employed was of such an excellent description as that obtained from South Wales.

The **President** observed that, in reference to the case that had been mentioned of the failure of marine boiler tubes after standing idle for a length of time, he had also met with an instance of the same sort, where the tubes had become very brittle after being left for a considerable time without getting up steam in the boiler; and the reason appeared to be that, as the boiler was covered with felt, there was always a slight dampness remaining inside around the tubes, although they were not actually surrounded with water. He enquired whether it was anticipated that the use of a higher percentage of copper would obviate this liability to rusting in marine boiler tubes when standing idle. In locomotive boilers the tubes were worked so much more severely than in marine boilers that any means of increasing their durability was of great importance, even if it involved some increase in first cost of tubes.

Mr. **Everitt** believed that the use of a larger proportion of copper in the tubes would render them less liable to rusting in marine boilers, when left standing in a damp atmosphere for a length of time.

Mr. J. **Fernie** thought the paper that had been read was one of much value in supplying practical data respecting the composition of boiler tubes; and the question of the quality of best selected copper was one of great importance also in the manufacture of gunmetal bearings for journals, consisting of an alloy of copper zinc and tin. In consequence of the frequent heating of railway carriage and wagon journals, he had himself made a number of experiments some years ago upon the composition of the gunmetal bearings; and he had found great difficulty in obtaining a quality of copper good enough for making the required description of gunmetal, which was owing without doubt to the excessive stripping for the production of the best selected copper.

Mr. A. **Muntz** believed that the composition of the best alloy for brass boiler tubes depended a great deal upon the quality of the water and coal used for working the boiler. If the water were at all of an acid character, it would not do to have tubes containing a very low percentage of copper, because they would become brittle; but any copper that was introduced beyond the percentage necessary to prevent the tubes from becoming brittle under the action of acid, which he considered to be about 62 per cent., would reduce the durability of the tubes, because the sulphur contained in the fuel would act upon them more rapidly, and the metal being softer would wear away sooner from the mechanical action of the blast.

In reference to the case mentioned in the paper of copper sheathing made in 1825 which had lost only ¼ per cent. of its weight after eighteen years' wear, he was not able to understand how the loss of weight could have been so small during that length of time; because with the present metal sheathing composed of copper and zinc it was found that if the metal was too poor, containing too small a percentage of copper, the ship's bottom fouled, from not oxidising sufficiently; and if the metal was too rich in copper, it oxidised too rapidly, and would thereby become speedily worn away. If therefore any sheathing had remained many years on a vessel, he thought it would either have fouled to a great extent, or have lost a great portion of its weight by oxidation.

Mr. E. A. Cowper observed that the case mentioned in the paper was by no means a solitary one, in respect to the durability of copper sheathing on ships in former years, as there were many instances of old copper sheathing that had worn for fifteen years and upwards; whereas copper sheathing made at the present time had an average duration of only four or five years, and there were many cases in which bad copper sheathing had had to be stripped off after only a few months' wear.

The President moved a vote of thanks to Mr. Everitt for his paper, which was passed.

The Meeting then terminated; and in the evening a number of the Members dined together in celebration of the Twentieth Anniversary of the Institution.

PROCEEDINGS.

4, 5, and 6 June, 1867.

The Annual Meeting of the Members was held in the Lecture Theatre of the Conservatoire Impérial des Arts et Métiers, Paris, on Tuesday, 4th June, 1867; John Penn, Esq., President, in the Chair.

The Minutes of the last Meeting were read and confirmed.

The President announced that the Ballot Lists had been opened, and the following New Members were duly elected:—

MEMBERS.

James Chapman Amos,	London.
Charles James Appleby,	London.
Thomas Welch Barrows,	Banbury.
Capt. Frederick Beaumont, R.E.,	London.
George Bernhardt,	Manchester.
John James Bleckly,	Warrington.
Samuel Chatwood,	Bolton.
William Clark,	London.
Francis Christopher Cockey,	Frome.
William Langton Coke,	Neath.
Thomas Fardon,	Leighton Buzzard.
Edward Field,	London.
Lavington Evans Fletcher,	Manchester.
William Lyster Holt,	Neath.
Thomas Ellwood Horton,	Lilleshall.
Robert Luke Howard,	London.
John Kellett,	Wigan.
Henry Lawrence,	Newcastle-on-Tyne.
Charles Lloyd,	London.
William Mather,	Manchester.

James McEwen,	Stourbridge.
Lewis Olrick,	London.
Daniel Pidgeon,	Banbury.
Samuel Radcliffe Platt,	Oldham.
John Pratchitt,	Carlisle.
Joseph Ruston,	Lincoln.
Charles James Sharpe,	London.
John W. Spencer,	Newcastle-on-Tyne.
Robert Stevenson,	Clay Cross.
Henry Swingler,	Derby.
Edmund Tonks,	Birmingham.
Henry Turner,	London.
Ralph Hart Tweddell,	Sunderland.
Charles Clement Walker,	Donnington.
William John Laverick Watkin,	Wigan.
Thomas Aldridge Weston,	Birmingham.
Thomas Wheatley,	Edinburgh.
Henry Wilson,	Stockton-on-Tees.

ASSOCIATES.

William Blinkhorn,	St. Helen's.
John Bonny Dewhurst,	Skipton.
William Alexander Neave,	Leeds.
Thomas Roe, Jun.,	Derby.

GRADUATES.

Nevil John Cuss,	Swindon.
James Charles Downes,	Derby.
Sidney Flavel, Jun.,	Tipton.
Henry Walker Hill,	Nottingham.
George Holland,	Manchester.
John Mitchell,	Barnsley.
John Edward Pearson,	Wigan.
Howard William Warden,	Tipton.

The following paper, by General Morin, Membre de l'Institut Director of the Conservatoire Impérial des Arts et Métiers, was the read :—

ON THE VENTILATION OF PUBLIC BUILDINGS.

BY GENERAL MORIN.

The renewal of air in buildings is only rendered necessary by the vitiation resulting from the respiration and exhalations of the occupants, and by the accumulation of the products of combustion from artificial lighting; and the writer has been led by his own observations and the consideration of the results obtained by others to the following conclusions as to the principles on which the ventilation of buildings should be based:—

First—Ventilation consists in getting rid of all vitiated air and replacing it by fresh air.

Secondly—The principal object of ventilation is to get rid at once of all vitiated air. It ought to be removed in general from the point nearest to the place where the vitiation takes place, in order to prevent any further diffusion into the room; and on the contrary fresh air ought to be introduced at the point furthest removed from the occupants of the room.

Thirdly—The different arrangements that proceed by *Suction*, when well proportioned and well carried out, are more effectual than those which depend exclusively on blowing in the fresh air, as the latter do not in every instance and at all times ensure the vitiated air being uniformly and continuously expelled.

Fourthly—The quantity of fresh air required, whatever may be the height from which it has to be drawn, and whatever the quantity, can be obtained by suction alone, and without the aid of any blowing apparatus, by giving to the inlet openings for the fresh air sufficiently large dimensions, and by suitable arrangement.

Fifthly—Suction can easily be obtained either by means of the ordinary open fireplaces with chimneys or similar heating apparatus, or by means of special fireplaces placed at the bottom of the exhausting flues and acting as auxiliaries when the rooms are large. The air to be removed ought to flow towards the bottom of these fireplaces, and wherever possible by means of special air flues leading from openings close to the sources of vitiation.

Sixthly—Ventilation by suction by means of fireplaces and chimneys can be adapted to the proportions and arrangements of every kind of room, as it resembles the ordinary and natural ventilation of rooms, and the volume and temperature of the fresh air supplied can be varied as required. It only requires the construction at a small expense of fireplaces with their chimneys, and of air flues, which when once constructed cost but little to keep up; and also the regular feeding of the fireplaces, which any common attendant is competent to do. On the contrary, ventilation by means of blowing or other mechanical apparatus necessitates, besides the flues and chimneys common to both systems, the addition of blowing machines and engines with special air passages, special artisans, engineers, and firemen, and involves an extra cost for keeping up.

Seventhly—In hospitals with several stories, the blowing-in system does not afford the same guarantee as that of suction against the diffusion of the vitiated air from one room to another through the openings of the discharging flues, when it happens that the pressure and movement of the air of the room are disturbed by the opening of doors and windows.

Suction produced by simple fireplaces and chimneys, with sufficient area of opening for allowing the fresh air to replace the vitiated air, and without any mechanical apparatus, is consequently the most desirable means in the writer's opinion for effecting the ventilation of buildings, except in rare cases; and where special circumstances may necessitate the forcing in of fresh air by mechanical means, the action of a strong suction should also be added. This necessity never occurs in buildings where a continuous supply and removal of a nearly uniform quantity of air is required, but only when on the contrary this service has to be varied frequently between different portions of the same building, and when the quantities of air to be removed differ greatly from one day or from one hour to another; as in the case of the St. George's Hall, Liverpool, where mechanical ventilation exclusively is adopted, and the quantity of air required varies in the extreme proportion of 1 to 50. In such cases it may become necessary, or at least useful, to employ mechanical apparatus in addition to the action of suction, in order to ensure a sufficient supply of fresh air.

The following proportions for the quantity of air required to be supplied per hour for each person are based upon the results of a large number of experiments by different observers, and though higher than the rates formerly adopted are not in the writer's opinion at all exaggerated :—

Hospitals for ordinary patients	2000 to 2400	Cubic Feet.
Ditto, in cases of epidemic	5000	„
Workshops, ordinary trades	2000	„
Ditto, unhealthy trades	3500	„
Prisons	1700	„
Theatres	1400 „ 1700	„
Meeting Halls	1000 „ 2000	„
Schools for Children	400 „ 500	„
Ditto, Adults	800 „ 1000	„

The temperature of the air in places abundantly ventilated, and having a continuous renewal of the air, can be allowed to be maintained at a higher point than in rooms not well ventilated; but as a general rule the temperature should not exceed, in

Hospitals	61° to 64°	Fahr.
Workshops, Barracks, and Prisons	59°	„
Schools	66° „ 68°	„
Meeting Rooms	66° „ 72°	„
Theatres	68° „ 72°	„

The fresh air supplied should be at nearly the same temperature as the one to be maintained in the room; but this has to be increased to as high as 85° or 95° Fahr., if there is a large cooling surface of glass; or to be diminished where the room is heated by a large number of lights or a large concourse of persons. For the purpose of regulating the temperature, the supplied air, warmed by some heating apparatus, has to be received first into a chamber into which cold air can be introduced for mixing with it.

The following relations between the volume and temperature of the air and the areas of the air flues have been obtained from theory and practice combined:—

$$V = C \sqrt{(T - T') H}$$

$$Q = CA \sqrt{(T - T') H}$$

In which A = sectional area of the exhausting flue.
H = height of exhausting flue.
T = average temperature of air in flue.
T′ = temperature of external air.
C = coefficient, constant for each air flue as regards its proportions and arrangement.
V = average velocity of air in the flue.
Q = volume of air passed per second.

The results derived from these relations are that the velocity of the escaping current is proportional to the square root of the excess of the temperature of the heated air in the flue over the external air, and also to the square root of the height of the flue or chimney; and the volume of air extracted is consequently proportional in addition to the sectional area of the flue.

The position of the openings for the admission and removal of the air is a point of great importance; and none of these should be made at the level of the floor, as is too often the case, because they are then exposed to obstruction by sweepings and rubbish from the floor. The openings for the admission of fresh air, whether warm or cold, should be placed near the ceiling, or at such a height that no person may receive the impression of a draught. The openings for the abstraction of the air should on the contrary be placed generally in the lower part of the room.

The velocity of the air should continually increase through the several passages of the building, from its entrance to its final discharge, which is best effected by the use of a single shaft for taking off the air from the whole building; and the velocities should be about—

2·3	to	2·9	feet per second		at the entrance
3·3	„	3·9	„	„	in the first passage
4·3	„	4·6	„	„	in the second passage
5·9	„	6·6	„	„	in the discharging shaft.

These speeds can be easily obtained in most cases by an excess of 70° to 80° in the temperature of the discharging shaft over the external air, except in the case of theatres, where a difference of 95° to 105° is required, on account of the complication of the passages. When the supply openings are in the ceiling, so that the air descends vertically, the velocity of the current entering through them should not exceed 1·6 feet per second; but when the air enters at the sides of the room at a considerable height the velocity may be as high as 3·3 feet per second without causing inconvenience. The plan of ventilation by suction has been objected to as causing objectionable draughts of air when doors are opened communicating with the exterior; but this sensation of draughts is got rid of when suitable proportions are adopted, and when care is taken that the passages communicating with the exterior are suitably warmed. The ordinary chimneys of houses produce in many cases a sufficient abstraction of air even without a fire, from the ordinary difference of temperature between the internal and external air; and this ventilating power can easily be increased by introducing into the chimney a vertical pipe containing a few gas burners.

An example of the application to a large building of the principles of ventilation described in the present paper is shown in Figs. 1 to 3, Plate 11, which represent the Public School in the Rue des Petits Hôtels in Paris. This building contains an elementary school A A for 400 children, and a drawing school B for 270 pupils. The ventilation is at the rate of 350 cubic feet per hour per person, and the warming is effected by two heating stoves C C with vertical tubes. The warmed air is supplied to each story by three vertical channels D, which discharge into a long wide passage E extending the whole length of the rooms, and into this passage external cold air can be admitted to regulate the temperature. The supply of air flows into the rooms horizontally near the ceilings, as shown by the arrows.

The rooms of the drawing school B are open at night, and offer special difficulties in ventilation, from the large number of gas burners in use. The plan of abstracting the vitiated air close to the floor cannot be exclusively applied in this case, as it would cause the discomfort of pouring down air of 85° to 95° temperature upon the heads of the occupants. It is necessary therefore to allow the heated gases from the combustion of the lights to escape through the openings F in the ceiling, but at the same time fresh air is made to enter at the sides near the ceiling. In such cases, when the room has not attics above it through which the outlet openings in the ceilings can discharge, special flues are required to be made for this purpose, and these should be situated as far as possible from the points where the admission of fresh air takes place. By means of this plan of ventilation the temperature of the above rooms has been maintained until 10 o'clock at night at 71° at a height of 5 feet above the floor, and at an average of 75° near the ceiling; but before this plan was adopted these temperatures were 80° and 91° respectively.

The discharge openings should be made along both of the longer sides of the room, as shown at G G in Fig. 1, and should be as numerous as possible; and their total effective area should be such as to limit the velocity of the air passing through them to 2·3 feet per second. They communicate with descending passages H, converging below into a main discharge passage K leading to the bottom of the discharging shaft J. The chimney pipes I from the hot-air stoves C are made to pass up this shaft for assisting the draught, but a small fire L at the bottom of the shaft is also requisite.

An example of the ventilation of a large meeting room is shown in Figs. 4 to 7, Plates 12 and 13, representing the Lecture Theatre of the Conservatoire des Arts et Métiers (in which the present meeting is held) and in which the ventilation arrangements have been carried out by the writer, and have been satisfactorily working for the last four years.

The vitiated air is taken off through a large number of orifices made in the risers of the steps A A, Fig. 4, opening into the space B below the seats, which communicates by an outlet passage C, Fig. 5, with the discharging shaft D; the requisite draught is maintained in the shaft D by means of a fire at the bottom, dampers being placed in the passage C to moderate the current of the air. The supply of fresh air is introduced from a mixing chamber E in the roof, and enters the lecture theatre through openings F F distributed over the surface of the ceiling.

In such buildings the ventilation should provide an amount of 1000 cubic feet of air per hour for each person, and the area of openings for the abstraction of the vitiated air should be sufficient to prevent its velocity through the openings exceeding 2·3 to 2·6 feet per second, the openings being distributed as uniformly as possible over the whole of the steps A A. The velocity of the air in the outlet passage C should not exceed 3·9 feet per second; and the velocity in the discharging shaft D should amount to 6·6 feet per second, in order to ensure the stability of the current.

The inlet openings F F for supply of fresh air, when situated in the ceiling, should have such an area as to allow the velocity not to exceed 1·6 feet per second; in this lecture theatre, where the total quantity of air admitted reaches 170 cubic feet per second, the area of openings slightly exceeds the above proportion. When it is requisite in such places for the inlet openings to be at the sides, they should be situated on two opposite sides, and as high from the floor as practicable.

As the ventilation of buildings like this lecture theatre is required to be in action only when they are occupied, whilst the warming is needed to be in operation previously to their occupation, it is necessary to have the means of warming them by special orifices, in addition to those which supply the ventilation. For the purpose of warming, the large hot-air stove G is employed, Fig. 4, situated under the lower end of the room; and the air necessary for combustion is supplied to it from the basement through the passage H. The fresh air to be heated is admitted through a separate passage I from the open courtyard adjoining, and after being heated by the stove is delivered into the room through the four openings J J in the floor; these are only opened during the preparatory warming of the lecture theatre while it is empty, and as soon as it is occupied they are closed. A constant supply of hot air is maintained to the two lobbies K K by the openings L L, and also by the openings M M to the laboratory N at the back of the lecture theatre; this prevents any objectionable draughts of cold air occurring whenever the intervening doors are opened during the occupation of the theatre; and the doors being all made to open outwards, the tendency of the entering air is to close them. At the upper end of the lecture theatre a similar heating stove is provided, but of smaller size, for warming the main entrance staircase and vestibule at that end of the room.

A portion of the hot air from the stove G is conveyed by the ascending pipe P to the mixing air chamber E in the roof; and in order to ensure its equal diffusion over all parts of the lecture theatre, the mouth of the hot-air passage Q is widened out to the full width of the air chamber E, as shown in the plan, Fig. 6; while a hood R is placed over the central inlet opening F, and screens S S are interposed at the two side openings, in order to prevent an undue proportion of the fresh warm air from entering the lecture theatre through these three nearest openings. A branch from the hot-air passage Q to the two side openings T T, Fig. 7, ensures a proper supply of hot air to each of these openings. A similar supply of hot air is introduced at the other end of the roof by the passage V from the smaller heating stove at that end of the lecture theatre. The fresh cold air is admitted into the roof chamber E through the entrances U U, Figs. 4 and 7; and by the arrangement shown in the drawings of the hoods R and screens S at the ceiling apertures, the thorough mixing is ensured of the cold and the heated air previous to entering the lecture theatre, the orifices of the hot-air passages Q and V being situated in all cases close underneath those admitting the cold air. By means of the valves U U the entrance of the cold air to the mixing chamber E is regulated according to the temperature desired in the mixed air introduced for ventilation; in winter this temperature should be about $3\frac{1}{2}°$ below that maintained in the lecture theatre, which should be about 68°.

The ventilation of a large theatre is illustrated by Figs. 8 and 9, Plates 13 and 14, representing the Théâtre Lyrique in Paris, in which the principle of the writer's plan of ventilation was adopted;

but this was unfortunately only partially carried out in the details, so that the full advantage is not realised in the results.

The number of seats in this theatre is 1470. For the ventilation of the stage and its dependencies, special means have to be applied by an auxiliary discharge flue above the stage, intended for use when required to remove any large quantities of smoke from extensive illuminations. In the body of the house, where the maintenance of a constant ample ventilation is required, there should be a supply of fresh air of 1400 cubic feet per hour for each person, with the means of increasing this in summer to 2000 cubic feet per hour. It is important for the supply of fresh air to be obtained from open spaces or gardens, if possible, or else by special shafts bringing the air from a point above the buildings, and far removed from the outlets of vitiated air. In the case of the theatre shown in the drawings, the inlet for fresh air is made in the square of the Tour St. Jacques, by means of a well 11½ feet diameter, communicating by a tunnel A of the same area with the space underneath the theatre, Fig. 9, where the warming apparatus and the mixing air chambers are situated. The velocity of the current in the inlet passage A was ascertained to be 3·08 feet per second in a special examination that was made some years since, and the sectional area of the passage being 97 square feet, the volume of fresh air admitted amounted to 300 cubic feet per second, which was somewhat in excess of the quantity that the apparatus was designed to supply. This area of inlet however has subsequently been allowed to be contracted considerably by the growth of ivy at the entrance.

The admission of the fresh air to the body of the house from the main supply shafts P P, Fig. 8, takes place between the floor joists or through the false bottoms made under the floors of each of the rows of boxes and gallery, as shown by the arrows at B B, Fig. 9, the air entering horizontally all round the theatre through these spaces, which should not be less than 5 to 6 inches clear height. The fresh air is also admitted by openings from about 10 feet height in the vertical walls on each side of the stage, and also by auxiliary channels under the flooring of the passages, intended specially for extra summer ventilation, and controlled by valves. For preventing the occurrence of unpleasant draughts upon the opening of doors into the exterior passages, these passages have to be warmed to a temperature of about 68°, and inlets of warm air are provided opposite the different doors in the passages.

A portion of the air, on entering by the main inlet passage A, Fig. 9, is warmed by traversing two sets of heating apparatus C C placed in the basement; and the remainder is delivered into mixing chambers for regulating the temperature of the air supplied in the building. The area of passage through the heating apparatus is 97 square feet, and the volume of warm air supplied is 245 cubic feet per second, giving a velocity of current of 2·5 feet per second.

The vitiated air is taken off through numerous openings in the lower part of the sides of the boxes and passages, and in the risers of the steps in the gallery, each box or pair of boxes having a separate discharging flue; and the total area of these openings has to be such as to allow the velocity of the air not to exceed 2·3 to 2·6 feet per second. The exhausting flues E E from the several tiers of boxes are made to rise towards the dome F above the chandelier, while those from the pit, orchestra, and boxes on the ground tier are carried below the floor into main flues leading to the vertical shafts G G; and the area of these exhausting passages should be such as to give a velocity of current of 3·3 to 3·9 feet per second. In the pit and orchestra, outlet gratings should be placed all round the sides, and in the sides of the air passages underneath the seats; these outlets open into the space left under the floor, which leads to the main exhausting shaft G on each side, this space being divided accordingly into two portions by the central partition J. The outlet gratings should not be placed in any case in the floor, as was done in this theatre, contrary to the writer's intention.

The cast-iron chimney pipes I I from the heating apparatus are carried up the exhausting shafts G to aid the draught, the pipes being kept isolated throughout; and a small firegrate H is placed at the bottom of each shaft, for use when extra ventilation is required in summer. The area of the exhausting shafts G G is required to be such as to give a velocity of current of 5·6 to 5·9 feet per second;

and they should lead, when possible, to the dome F over the centre of the theatre, into which all the outlet flues from the upper tiers of boxes also discharge. The general outlet shaft K above this dome should be built of brick, not metal, and should be carried at least 20 or 25 feet above the top, its area being such as to give a velocity of current of about 6·6 feet per second.

A series of experiments on the ventilation were made on five successive nights in May, 1863, with the external temperature ranging between 56° and 74°; and the result obtained was that with an average consumption of 4 cwts. of coal per night, costing 7*s.* to 8*s.*, the removal of 166 cubic feet of air per second was effected, amounting to 1400 cubic feet per hour per seat of the pit and orchestra. With this ventilation the temperature of the house can be maintained within comfortable limits; but this extent of ventilation is not actually employed, as the intended use of the two large exhausting shafts G G is not carried out. The experiments made at the same time on the ventilation of the boxes showed that an abstraction of 377 cubic feet of air per second was effected by the centre shaft over the dome, amounting to 1800 cubic feet per hour per seat. The actual average ventilation for the whole house during the five evenings was found to be 1330 cubic feet per hour per seat. By this uniform ventilation the temperature in the different rows of seats was maintained most remarkably constant, the average temperatures in the first and fourth tiers being 68° and 70° respectively, when the external temperature was 52°; and when the latter was 70°, their temperatures were 78° and 80° respectively: in other large theatres however, which are not so ventilated, these temperatures are not unfrequently as high as 95° to 105°.

At another trial in November 1863, when the external temperature was as low as 39°, the temperatures within the house were found to be maintained at

66° on the Stage.
71° in the Orchestra Stalls.
73° " " Boxes.
74° " " Gallery.

The above results show the satisfactory manner in which the mode of ventilation that has been described effects the objects intended; but the full benefit of these results is unfortunately not received in the present case, from the arrangements being only partially carried into regular use; and it has to be remarked that however perfect the ventilating arrangements may be in the construction of a building, it is indispensable that the working of them should be under the constant charge of properly qualified and responsible management, in order to ensure the desired object being systematically attained.

The PRESIDENT said they were greatly indebted to General Morin for his kindness in granting the use of the Lecture Theatre in which they were now assembled, and for the valuable facilities afforded by him for the present Meeting in Paris, as the Director of the Conservatoire Impérial des Arts et Métiers. The efficiency of the system of ventilation carried out upon the principles advanced in the paper, with which General Morin had favoured them, was practically illustrated by the agreeable condition and temperature of the air at the present moment in the Lecture Theatre, notwithstanding the number of persons now assembled in it on a summer day.

GENERAL MORIN expressed his pleasure in welcoming the Members of the Institution on the occasion of their Meeting in Paris, and his gratification in receiving them at the Conservatoire.

Mr. EDWIN CHADWICK remarked that the two opposite systems of ventilation—the one by propulsion or driving in the air by mechanical means, and the other by suction or creating a draught by heating the air in the discharge flues—might both be seen in operation in Paris, in different wards of the Lariboisière Hospital near the Northern Railway Station; there had been considerable controversy respecting the relative advantages of the two plans as carried out in that building, and he did not know of any better practical example of the two methods. The fresh air supplied by propulsion was warmed, and driven in by engine power by means of a fan; and in abstracting the vitiated air by suction, it was taken off close to the points of greatest vitiation, namely between each of the beds in the ward. From a careful examination made of the subject by physicians he had been led to conclude that the system of suction, as described and advocated in General Morin's paper, was not only the most economical, but also the best in regard to the degree of purity maintained in the air of the building, as the system of propulsion was found to be attended with the disadvantage that the current of fresh air driven into a room would sometimes pass through direct to the outlet, without thoroughly expelling the vitiated air, and thus allowed an objectionable accumulation of vitiated air to take place in particular portions of the room. The arrangements for ventilation by suction at the above hospital had been developed and carried out with very decided success by the late M. Léon Duvoir, who had undertaken to give a supply of 2000 cubic feet of air per hour for each bed in the wards, heated to a uniform temperature of 60° Fahr., at a charge of 1*d.* per bed per day; and the actual cost he understood had been found to be only about half that amount, the price of the coals used being about 40*s.* per ton in Paris at the time. The rarefaction necessary for effecting the ventilation was obtained by means of a hot-water tank at the top of the building, and the ends of the air flues being carried up through this tank by means of thin iron pipes, an upward current of air was established by the heating of the air within the flues, whereby the vitiated air was abstracted from the building with a uniform draught, as tested by holding a lighted candle at the bottom of any of the air flues. In some cases the vitiated air was taken off upwards, and in others downwards, and the ventilation was effected with complete success in each way. For the purpose of saving heat, a coil of water pipes or a water jacket was placed round the chimney of the furnace employed for heating the water in the hot-water tank, and by this means nearly two-thirds of the heat escaping into the chimney was found to be saved. The fresh air admitted to the building was warmed by being made to pass between a number of thin iron pipes containing the heated water supplied to the hot-water tank. The warming of the Madeleine Church, containing 2,000,000 cubic feet of space, had also been undertaken by M. Duvoir at a cost of 11*s.* 2*d.* per day; and also the ventilation and warming of the Palais de Justice, a prison, and several other public buildings, as well as a number of private houses: the warming of eight-story houses had been undertaken by him at from 3*s.* to 4*s.* per day, and the very small quantity of coal consumed for the purpose was remarkable. On a small scale the same principle of ventilation by suction might also be carried out by simply placing a lighted lamp or candle in the bottom of a properly constructed air flue; or by building air flues parallel and contiguous to the chimney flues, so as to be heated by the latter. The simple manner in which the ventilation by suction had been carried out in the Lecture Theatre of the Conservatoire under General Morin's directions, the ventilation being completely maintained without requiring special attendance, appeared to him to be much in advance of any attempts that he had met with previously; and he thought it would be a great benefit if the same plan could be introduced in England for the ventilation of public buildings.

In conjunction with the ventilation of buildings, the warming of the air supplied had hitherto been the chief subject of attention in France and England and other northern countries; but for hot weather even in this climate it was desirable that attention should be given to the corresponding question of cooling the air, and in the tropics this was an absolute necessity. In an experiment made by M. Duvoir at the Palais de l'Institut on cooling the supply of fresh air by passing it between a series of pipes through which a stream of cold water flowed, the meeting hall had been cooled down to a considerable extent on a hot summer day, while occupied; and this result deserved the particular attention of any one entrusted with the ventilation of buildings in India or other tropical countries, where the effectual cooling of the air was of such great importance.

Mr. J. WHITLEY concurred in the importance of having a system of ventilation not requiring constant attention, particularly for private houses, where such attention was out of the question. Having himself carried out for house ventilation in a large number of cases the principle of suction advocated in the paper, he had found that, by simply taking advantage of the rarefaction produced by the ordinary chimneys, sufficient exhausting power was available for ensuring a constant supply of fresh air in all the rooms and passages of a house; and by this means a room closed and fully occupied for a length of time, such as a sleeping apartment, was made to retain as pure an atmosphere as if unoccupied. In the plan that he had used, a suitable outlet from the room into the chimney was made at the level of the ceiling for the escape of the vitiated air, and a corresponding inlet for the fresh air was made in a distant part of the room; and whenever the chimney was not heated by a fire in the room, a jet of gas lighted at the bottom of the inlet to the chimney was found sufficient to produce the necessary amount of rarefaction, as named in the paper.

Mr. **Bramwell** enquired whether it had been found necessary, in the system of ventilation described in the paper, to introduce any moisture along with the supply of air artificially heated.

General Morin replied that he had not found any necessity for introducing moisture with the air supplied, because he had adopted the plan of heating only a small portion of the air, and mixing this with a quantity of fresh cold air, so that the mixture contained a sufficient supply of moisture to prevent any sensation of dryness, without requiring any addition of moisture by artificial means. When the whole of the air supplied was heated, as in the case of the British Museum, and St. George's Hall, Liverpool, it was generally found necessary to provide special arrangements for restoring to the air the degree of sensible moisture which it had previous to the heating process. But in most cases only a moderate amount of heating was required even in winter, as it was found that the air supplied should be introduced at a temperature of 3½° to 5½° Fahr. below that to be maintained in the building. In the case of the Lecture Theatre in which they were now assembled the extent of accommodation was limited to about 700 persons, but the ventilating arrangements had been carried out upon a scale which would be amply sufficient for an assemblage of 1200 persons.

Mr. C. W. **Siemens** thought there must be more need of moistening the air in winter than in summer, because at a lower temperature the point of saturation of the atmosphere was lower, and when below the freezing point it was devoid of moisture altogether; while at the same time there would then be the greatest proportion of heated and dry air to be mixed with it. He enquired whether in winter there was ever found to be any necessity for adding moisture to the air.

General Morin replied that in a room containing only two or three persons it might under such circumstances be desirable to moisten the supply of air, because the quantity of moisture exhaled in respiration was not then enough to saturate the air. But in an assembly of a great number of persons there was an objectionable excess of moisture in the atmosphere from exhalation; and therefore in most cases, instead of adding moisture to the air, the object to be aimed at he thought was rather to introduce dry air, with a view to get rid as far as possible of the excess of moisture already existing in the atmosphere of the room.

Mr. C. W. Siemens enquired in reference to the plan that had been mentioned, of cooling the supply of air for ventilation in hot countries, whether General Morin had made any experiments on that subject, and whether the mode of carrying out the system of suction would be the same in that case, by introducing the cold fresh air at the ceiling and drawing off the vitiated air below, or whether the arrangement would have then to be reversed. It would be very advantageous he considered if the plan of introducing the fresh air at the ceiling could still be adhered to.

General Morin replied that an illustration of the supply of air for cooling purposes was afforded by the Lecture Theatre in which they were now assembled, where the internal temperature was at all times of the year above the required degree when the room was fully occupied, and needed always to be kept down by a liberal supply of fresh cool air, which was introduced at the ceiling, the ventilating arrangements in this case having been completely carried out according to the system described in the paper. At the Corps Législatif on the contrary the cold air was introduced at the floor of the assembly hall, through very narrow openings of only about 1 inch height, situated in the risers of the steps; and the result had been the presence of very disagreeable draughts about the legs of people, showing the mistake of letting the fresh air enter at the floor. At the present moment the supply of fresh air in the Lecture Theatre was at the rate of as much as 13,000 cubic feet per hour per person; but as it was introduced at the ceiling of the room and through a number of large openings, there was not the slightest sensation of draught, while the atmosphere in the room was maintained fresh and cool. Even had the day been considerably hotter, the extent of ventilation provided for would have been sufficient to keep down the interior temperature below that outside. In special experiments he had employed the pipes of the heating apparatus for the converse purpose of cooling the air, by circulating a stream of cold water through them, and making the supply of air pass between them on its way to the entrances of the room. By this additional means, when the temperature in the room had been 68° Fahr. and the external temperature 66° Fahr., he had succeeded in reducing the internal temperature by 4° or 5° Fahr. In the case of intense summer heat or in tropical countries the requisite cooling effect might no doubt be readily obtained by having recourse to a fine spray of water in the main air passages in the basement of the building, just sufficient to moisten the whole of the surfaces over which the fresh air had to pass in entering, so as to bring into play the cooling effect of rapid evaporation. He had originally contemplated applying this mode of cooling in the ventilation of the Conservatoire, but he had found in practice that an ample cooling effect was obtained by the abundant ventilation, without the necessity of this additional provision for the purpose.

Mr. W. **Fairbairn** considered the subject of ventilating large public buildings was one of the greatest importance at the present day, and required serious consideration. In the paper just read he had been much struck with the large allowance of air stated to be required for the efficient ventilation of buildings where a number of people were congregated together, amounting to as much as 1500 to 2000 cubic feet per hour for each person. In the case however of a barracks in London, it had been found that the quantity of fresh air supplied was less than 500 cubic feet per hour per individual; and the result had been that men who came strong and healthy from the country became consumptive in a few months and a great number died, the rate of mortality being even greater in the barracks than on a campaign. He enquired whether the principles of ventilation enunciated in the paper had been applied to any of the barracks in Paris.

With regard to the mode of effecting the ventilation by introducing the fresh air at the ceiling and taking off the vitiated air at the bottom, this was a direct reversal of the plan generally adopted in England, of supplying the fresh air at the bottom and discharging the vitiated air at the top of the room, which he himself had hitherto been accustomed to consider the most natural way of ventilating a building. There was no doubt however that the system described in the paper possessed an important advantage in the very slow velocity at which the fresh air was brought in, amounting to only 2 or 3 feet per second; and it was evident that with such a velocity there was not much danger of any person catching cold in the room, as the speed was not sufficient to produce any sensation of draught. Moreover by removing the vitiated air at the bottom, the carbonic acid gas, which constituted the principal element of vitiation and naturally tended to the bottom by its greater specific gravity, was taken off at once, without contaminating the fresh air in the rest of the room; and this he thought was a very important feature in the system. A somewhat greater force of draught would of course be required to take off the vitiated air at the bottom instead of the top; but it was no doubt worth while to have rather more heating power for this purpose in the upcast shafts, on account of the advantage attending the immediate removal of the vitiated air at the bottom of the room. He hoped there might be opportunities of seeing the same mode of ventilation tried for public buildings in England, where there was at present so much room for improvement in that respect.

General Morin said he had seen the report of the English commission upon the ventilation and warming of barracks, and had been much interested in the excellent plan of ventilating chimney proposed for the purpose by Capt. Douglas Galton. Experiments had also been tried upon the subject in the Paris barracks near the Hôtel de Ville (Caserne Napoléon); but owing to some defect in the arrangements the direction of the current was found sometimes to reverse itself, bringing back the vitiated air into the building instead of carrying it off; and the men had suffered from ophthalmia in consequence. He had not yet had any opportunity of applying to barracks the system of ventilation described in the paper. The importance of taking off the vitiated air at the bottom of the room, whereby alone it could be removed at once without polluting the atmosphere within the building, was sufficiently demonstrated by a visit to the basement of the Lecture Theatre in which they were now assembled; and in simply passing along quickly under the seats of the theatre when occupied by a number of persons, he had felt completely stifled by the poisonous atmosphere drawn off from the room. It was not surprising therefore that in large assemblies persons were frequently made ill by mere defect of ventilation; and in the case of hospitals it appeared not unreasonable to suppose that the very walls of the building must become impregnated with infection. These difficulties he considered could only be effectually obviated by the system described in the paper, ensuring the immediate removal of all the vitiated air by taking it off at the bottom of the room.

The **PRESIDENT** moved a vote of thanks to General Morin, which was passed, for his kindness in contributing the valuable paper that had been read, and so actively promoting the interest of the Meeting of the Institution in Paris.

The following paper was then read :—

ON FLOATING DOCKS, AND OTHER ARRANGEMENTS FOR AFFORDING ACCESS TO SHIPS FOR EXTERNAL REPAIRS.

By Mr. **FREDERICK J. BRAMWELL**, of London.

For the purpose of affording access to the immersed parts of vessels, there can be little doubt that in the early periods of navigation the vessels were either hauled up on the beach for examination, in the absence of rise and fall of tide; or, where there was a considerable rise and fall of tide, the vessel was placed over a flat beach at high water, and allowed to ground as the tide fell. Although the latter plan is easy of application, and useful to a certain extent even for large vessels, where there is a considerable rise and fall of tide, the former mode must have been difficult to carry out except with very small vessels; and therefore it is probable that the plan of "Careening" was resorted to as soon as vessels were built of any considerable size.

This plan, more properly called "heaving down," was carried out in two ways: either as shown in Fig. 1, Plate 15, by bringing the ship near a quay wall provided with mooring rings and capstan, and attaching ropes to the heads of the masts, so as to haul the ship over into a nearly horizontal position on the water; or as shown in Fig. 2, by putting the heaving-down tackle on board another vessel, so that the operation could be performed independently of the land. This second plan had the advantage of being also independent of the rise and fall of the tide, which in the other method of course affected the position of the ship under repair.

The plan of "careening" seems to have been extensively practised in the naval arsenals of France at an early date. Whether done by tackle from the land or from a vessel afloat, the operation was of course aided by the removal of the ballast and heavy weights, so as to lighten the ship. By the mere shifting of the weights and without the assistance of tackle, a large amount of the ship's surface could be exposed; but this plan was of necessity attended with considerable danger of foundering, as exemplified in the fate of the "Royal George," which foundered at Spithead in August 1782, with upwards of 600 persons on board, whilst being careened. Careening is also stated to have been the cause of permanent distortion in the shape of vessels, from the exposed side being strained to an unnatural degree of convexity prior to the driving in of the caulking, which then kept the vessel to the distorted figure it had assumed.

The next mode to be mentioned is the ordinary Graving Dock or Dry Dock, which even at the present day is the plan most commonly employed in Europe, and will probably continue to be preferred in all places where there is a large rise and fall of tide, and where the ground is suitable for excavation. As regards the derivation of the term "graving" dock, it has been suggested that the name was taken from the resemblance which the dock bore to a "grave;" but the writer believes it to be derived from the operation carried on in the dock, as it appears from records of the date 1667 that what is now called "paying" a vessel with a composition was formerly called "graving;" and it would seem that this word is of French origin, and in turn owes its derivation to the place where the graving was sometimes performed, namely on a flat sandy beach or "grève." As early as 1623 there was a dry dock at Deptford, and in 1667 there was one also at the arsenal at Rochefort in France.

Various kinds of graving docks have been either executed or proposed. In many parts of England the rise and fall of the tide are sufficient to admit of a very large vessel being drawn into a dock at high water, so as to be brought over the keel blocks, on which it then settles down as the tide recedes, and at low water the dock is left dry and the vessel exposed for repairs; the sluices being then closed exclude the water, so that the succeeding tides cause no interruption to the work. But in situations like the shores of the Mediterranean and in other places where the tide is but small, the water has to be got out of the dock by pumping, which before the days of steam power was found both an expensive and a tedious process, causing great delay before the vessel could be reached even for slight repairs or merely for inspection. To make the operation more expeditious, large chambers have in some instances been provided below the level of the dock, sufficiently capacious to receive from the dock the whole or the greater part of the water contained in it, which could afterwards be pumped out of them at leisure. This plan certainly gave the advantage of speed in emptying the dock, but it added largely to the first cost, and moreover caused the labour of pumping to be increased, owing to the greater depth from which the water had to be drawn; nevertheless these chambers were in use at Toulon and also at Portsmouth, notwithstanding that at the latter port there is a rise and fall of about 10 feet at ordinary spring tides.

Where there was a lofty shore and a supply of water from a high level, it has several times been proposed, and amongst others by Belidor, to make dry docks as shown in Fig. 3, Plate 15, where A represents the ordinary sea level, and B a low-level dock opening into a basin in connection with the sea, and having its sides C as much above the sea level as would equal the draft of the largest ship to be docked. D is an upper dock, having the top of its sides level with C, and its floor a little above the sea level A. If a ship be floated into the lower dock B and the gates be then shut, and if water from a high level E be allowed to flow into B and D, the water will continue to rise and the ship will be lifted until its keel is high enough to pass over the blocks on the floor of the upper dock D, when it can be hauled into that dock and the sluice of the lower dock B opened so as to allow the water to escape into the sea, leaving the ship securely berthed in the raised dock.

In some few favourable situations graving docks are comparatively simple to construct and maintain, namely in such situations as Birkenhead, where the docks are hewn out of the solid rock, which while it is sufficiently hard and homogeneous to support the heavy weights is sufficiently soft to be readily worked. In these cases there are none of the dangers to be apprehended of settlement or of blowing up the bottom that exist where the dock is built in an excavation made in the earth, which is frequently of an extremely treacherous character at river sides. As regards the mode of closing the entrance to dry docks, this has been effected either by Gates to open sideways like those of a lock, or to fall upon the bed of the river, or by Caissons. The latter, now that the introduction of iron for ship-building purposes has admitted of their being made of that material, are almost universally adopted for large docks, and have the advantage of affording the means of retaining water inside the dock as well as of keeping it out, which is of considerable importance for allowing time enough to adjust the ship properly before it settles down on the keel blocks. Among the largest graving docks may be mentioned the double dock now constructing at Brest, 721 feet long and 92 feet wide, with 35 feet depth of water over the cill; and the double dock at Portsmouth, which is 636 feet long, 88 feet wide, and 27 feet deep over the cill: and one of the largest single docks is that at Devonport, which is 415 feet long, 73 feet wide, and 32 feet deep over the cill.

The hauling up of ships appears to have been practised from a very early period in the Venetian arsenals, and also at Toulon in France, where it was applied in 1818 to a large vessel; but the ships seem to have been only brought over an ordinary building slip, and then hauled up on the ways, being steadied by a sort of sliding cradle.

A special construction of carriage for this purpose was invented in 1818 by Mr. Morton of Leith, which is shown in Figs. 5 and 6, Plate 16. An inclined slip-way A is formed on a slope of about 1 in 20, and provided with rails on which travels the wheeled carriage B, the railway being extended sufficiently below the water to admit of the ship being floated over the carriage. By then hauling up the carriage by the chains and capstan gear C, the ship being attached to the chain is drawn up out of the water and above the influence of the highest tide, and is blocked up upon the floor of the slip so as to admit of the carriage being removed. To prevent the ship from heeling over while in the act of being hauled up, the carriage is provided with bilge blocks D sliding on timbers transverse to the slip. As the ship settles down on the keel blocks and before she is removed from the water, these bilge blocks D are hauled in until they support the bilges, the hauling being done by ropes led up to the deck of the ship. This appears to have been the first use of proper bilge-block shores which could be applied while the vessel was still afloat; and in the writer's opinion such a mode of sustaining vessels at the bilges before the water support is taken away is of the greatest utility, on account of its importance in preventing undue straining or risk of heeling over. In ordinary graving docks, it is true, bilge shores are used; but they are not applied until the water has been removed from the dock, and therefore not until after the ship has been subjected to the strains arising from the weight of her contents without her natural water support.

Morton's slips, which are now in extensive use, were at first intended only for small vessels, but they have lately been constructed for ships of 2000 to 3000 tons burden. With small vessels little difficulty was experienced in building the slips, especially where there was a considerable rise and fall of tide, because the lower part of the slip could be constructed at low water; but when the longer modern vessels were required to be taken up, the length of the slipway below the water became very great, as a slope of 1 in 20 requires the length of slip below water to be 20 times the draft of the vessel merely to reach her stem, and the slip must then be carried still further to extend under the length of the vessel. As this portion had to be constructed by the aid of divers, and its execution was attended with serious difficulty, it has been proposed to shorten the slip in the three ways shown combined in Fig. 7, Plate 16. The first plan is to make the slip of a curved form, giving a steeper slope to the upper portions of the slip, so that the length below the water line is not so great as if the slope had been continued uniform up from the bottom end; the second mode, intended for places where there is a rise and fall of the tide, is to enclose the upper part of the slip within water-tight walls and to employ gates for shutting out the water; and the third plan is a telescopic construction of the cradle on which the ship is lifted.

In Fig. 7 the ship is shown partially raised, and with all the lengths of the telescopic cradle fully drawn out. A A represents the surface of the slip made to a curve; E the gates, placed just below where the vessel will be when fully hauled up; B the telescopic cradle, composed of lengths attached to each other by rods F, so that when it is lowered it may rest at the bottom of the slip collapsed to about one half its full length. As soon as the stem of the vessel takes its bearing on the first section of the cradle and the hauling commences, this first section is drawn out from the second to the full extent of its coupling rods, and the second is then drawn out from the third, and so on; the result being that the vessel is securely taken up on a cradle requiring no greater length of slip-way below the ship than half the length of the ship. By these various contrivances the length of slip has been considerably shortened from what it would have been if constructed on the original system unaltered; but as regards the dock-gates and the water-tight side walls, it may not unfairly be said that their use is inconsistent with the employment of a simple slip, nor indeed could they be resorted to in a tideless sea without the expense of pumping apparatus to empty the upper part of the slip.

The application of this slip to vessels of a larger class soon rendered some improvement necessary in the simple hauling chain that had sufficed for ships of 200 tons. A set of traction rods was first substituted for the body of the chain, and was hauled in by a short flat-linked chain working over a pitched wheel driven by gearing. The end of this flat chain was first attached to the foremost rod, and then hauled in until the second rod was brought up to the place of the first, when the flat chain was overhauled and made fast to the second rod; and this operation was repeated with the successive traction rods until the ship was fully drawn up. A further improvement consisted in making the flat-linked chain endless, so as to avoid the necessity of overhauling it. For some time past however the larger slips that have been erected have been worked by the direct application of hydraulic rams to the ends of the traction rods; and among other plans double presses have been employed, made to work alternately, so that the hauling up might be nearly continuous.

An important adjunct to the slip is an arrangement of transverse lines of rails in the building yard at the upper end of the slip, so that by the use of carriages the vessels hauled up can be shifted sideways, thereby enabling a single slip to serve for hauling up several vessels in succession, so that their repairs may be going on at the same time.

The simple plan already mentioned of placing a ship on a beach at high water, so that it may be left dry at the ebb, is still used where there is a considerable rise and fall of tide; and to enable it to be carried out without risk of unequal support to the ship, a regular open framing of beams is made on the beach, called a "gridiron," by means of which vessels can be blocked up, and properly examined and repaired at low water. There is of course the objection that at the rise of each tide the work has to be suspended; but nevertheless the system is so simple and inexpensive, and the vessels are so readily got off and on, that it still continues to be used.

In the plans previously referred to for lifting vessels out of the water, the vessels have been hauled up on an incline; and in the class of Direct Lifts, which has now to be considered, the earliest is that of Mr. Alexander Mitchell, the inventor of the screw pile, who in 1833 proposed to employ the rise and fall of the tide for raising vessels out of the water by the means shown in Fig. 4, Plate 15. Two parallel rows of piling A A are placed sufficiently wide apart to admit the vessel between them; and B B represents a permanently buoyant floor, made of light materials or of caissons. On the ebb of the tide this floor sinks between the piles, and at low water pins C C are fixed in the piles above the flooring. When the tide next rises the floor is held down by the pins, and at high water the vessel is brought over the floor and allowed to settle down on it, being maintained in an upright position by shores from the piles. At the next ebb the ship is duly propped up by bilge shores from the floor; and the side shores being then removed and the holding-down pins withdrawn, the flooring is lifted by the next rising of the tide, taking up the ship with it, which rises and falls with the buoyant flooring at each tide until the repair is completed, when the flooring is again held down for the vessel to be floated off at the next high tide. This plan is evidently not suitable for cases requiring rapid access, as it needs at least three low and three high tides for enabling a vessel to be got on and off.

In 1827 a Screw Lift was constructed in America for raising vessels independent of the tide. This is shown in Fig. 10, Plate 17, and consisted of a platform A on which the vessel was to be lifted, the ends B of the transverse timbers of the platform being steadied by two parallel rows of piles C C, placed far enough apart to admit the vessel between them. The longitudinal timbers which connected the heads of the piles carried a number of vertical screws, as many as 46 having been used in one instance, the lower ends of which were connected to the transverse timbers of the platform, so as to raise the vessel out of the water. Since 1836 however this lift has been worked by means of hydraulic presses. Fig. 11 shows the arrangement which the writer saw at work at New York in 1853. Chains shown by the dotted lines are attached to the ends of the transverse bearers B B of the platform, and pass over pulleys to the long traction bars D, the land ends of which are connected to the hydraulic presses E for lifting the platform with the ship upon it.

In 1842 an improvement upon the screw lifting dock was proposed by Mr. Robert Mallet, which is shown in Fig. 9, Plate 16. The framework B on which the ship is to be raised is carried on a number of supports C C, hinged at their lower ends to eyes D supported on the rock or on piles, and at their upper ends to the frame B, forming a sort of parallel-ruler motion. The slings E attached to the top of the supports C are provided at their upper ends with rollers, which run within a tubular rail F having a continuous slot on its underside, as shown to a larger scale in the section Fig. 8; and the slings are hauled in by the chains G worked by powerful steam winches. The frame B being lowered and the ship drawn over it, the chains are then hauled in, so as to pull the slings horizontally, thereby raising the framing until the ship is lifted out of the water. This arrangement has the advantage of giving a nearly uniform strain on the chains and machinery throughout the lifting of the vessel, inasmuch as at the commencement, when the supports are nearly horizontal and carry but little of the weight, the slings are vertical and the weight of the ship is almost entirely carried by the water; while by the time the ship has lost the support of the water and the slings have become inclined, the supports have assumed a position more nearly upright, and therefore, although the whole weight of the ship has now to be borne by the lift, the proportionate strain coming on the chains is but small.

In the lift designed by Mr. Scott in 1850, and shown in Fig. 14, Plate 18, the ends B B of the cross timbers of the platform A were attached to slings depending from the crossheads of a number of vertical hydraulic presses C C, the stroke of the presses being equal to the lift of the vessel. It was intended either to repair the vessel on the platform, or to move it off on railways either endways or sideways, so as to make one lift answer for the simultaneous repair of several vessels.

The ship lift of Mr. Edwin Clark, which was put to work at the Victoria Docks, London, in 1857, is shown in Figs. 12 and 13, Plate 17. The two parallel rows of cast-iron columns A A contain hydraulic presses, and the slings from the crossheads of the presses are attached to truss girders B B which extend from side to side of the dock. If the lift be used at a place where repairs are not frequent, these girders carry the framing on which the ship is to be lifted; but if the lift is expected to be much used, as in the case of the Victoria Docks, then these cross girders carry a saucer C or shallow wrought-iron vessel of sufficient capacity to float the largest ship which can be taken on the lift. The girders being down and the saucer upon them, the ship is floated and adjusted over it; and the hydraulic presses being put to work, the saucer is raised until the blocks touch the keel of the vessel; bilge blocks are then drawn in against the vessel, and the working of the presses is resumed until the saucer is raised above the water. The saucer is provided with large valves, which are opened during the time of raising, so that the water runs out as the saucer rises; but as soon as the saucer is fully up, these valves are closed, and then the repair is either done on the lift, or else the girders are lowered again and the saucer left floating with the ship on it. The saucer is then hauled away to one of the basins D D, Fig. 13, which it just fits both in surface dimensions and draft of water; and the repairs are executed there, leaving the lift at liberty to be used for other vessels. At the Victoria Docks there are now eight of these saucers in use.

Another lift that was erected in the London Docks consisted of a pontoon carrying a deck, over which the vessel to be raised was hauled, the pontoon at the time being full of water. When the vessel was adjusted over the pontoon, the water was pumped out from it, and then the pontoon rose, lifting the vessel with it. To preserve the surface of the pontoon horizontal in rising, a number of parallel-ruler joints were connected to the pontoon and to eyes at the bottom of the basin. Unfortunately this apparatus failed before any ship had been docked upon it. The failure is believed to have been due to a want of strength in the parts, as the pontoon on being lowered sprung so serious a leak that it became impossible to raise it again, and it remains a wreck to this day.

In each of the various plans already considered, with the single exception of careening by the aid of another vessel, it has been necessary that there should be some connection with the solid ground; but Floating Docks properly so called dispense with the necessity of any such connection with the land for the purpose of support, as the dependence for support is on the water alone, the only requirements being a sufficient depth of water and a holding ground to which the apparatus can be anchored.

As early as 1785 a Floating Dock was constructed by a shipbuilder named Watson at Rotherhithe, which is shown in Fig. 15, Plate 18. It consisted of a timber vessel, 245 feet long, 58 feet wide, and 23 feet deep on the blocks, having an open end which could be closed by gates. Water being admitted into the vessel to sink it to a sufficient depth, the gates were opened, the ship to be repaired was drawn in, and then the gates being closed and the sluices shut the water was pumped out, leaving the ship in the interior of a true floating dry-dock. Mention is made of one vessel, the "Mercury," having been docked in this dock with great success. No provision appears to have been made to regulate the descent of the dock nor to prevent it from sinking too low, and it is to be assumed that the material employed being wood was in itself sufficient for this purpose. Docks of a similar character have been constructed at various times and places; but in order to ensure stability they have been sunk between guiding piles upon a level bed, and were therefore not true floating docks, that is, docks independent of the land. Such a dock it appears was proposed to be constructed for the port of Havre about 1848.

In 1809 Trevithick and Dickinson designed a floating dock or caisson of wrought iron, with air chambers at the sides for floating the dock when its body was full of water. It was then to be sunk by admitting just as much water into the air chambers as was required for making it very slightly in excess of the specific gravity of the water; and the ship being brought over it, the caisson was to be raised by ropes until its top edge was brought just above the surface; and then the water was to be pumped out of the body of the dock, so as to make the caisson rise all round the ship, leaving the ship accessible for repair. The size of caisson proposed was 220 feet long, 54 feet wide inside, and 30 feet deep, the top being surrounded by a flat rim 6 feet wide to serve as a working platform and also to strengthen the edge. The record of this idea appears to possess considerable interest, as showing that even so early as 1809 the possibility of constructing a wrought-iron caisson of these large dimensions was contemplated.

The Sectional Floating Dock, invented about 1837 in the United States, is shown in Figs. 16 and 17, Plate 18. The sections AAA, from which the dock takes its name, are each composed of a bottom caisson B, on the ends of which are raised frames C C carrying platforms and houses D D. The frames are made high enough for the greatest depth to which the dock has to be sunk, so that the platforms and houses may at all times be out of the water. In the frames are placed air tanks E E, capable of vertical movement within the frames; or rather the frames are capable of movement past the tanks, as the latter remain without much variation in reference to the level of the water that the dock is floating in. The connection between the tanks and frames is made by means of rack and pinion gearing, worked off shafting which extends along the dock from the engines in the houses on the central section. The same shafting also works, in all the houses, pumps connected with the bottom caissons B. In applying this dock for lifting a vessel, a number of the sections are brought together and secured to one another by tie beams; and sluice valves being opened to admit water into the caissons B, the dock begins to sink. The gearing connected with the air tanks E is then put to work, so as to allow the tanks to remain at the surface of the water while the dock sinks to the desired depth, at which it is then held suspended by the air tanks. The sluice cocks are then shut, and the vessel is drawn into the dock and secured in a central position by "breast shores." The pumps are then all put to work to raise the dock until the vessel takes the keel blocks, when the bilge blocks are hauled in to support her, and the pumping is continued, causing the dock to rise, lifting the vessel with it. In the act of rising the whole is in a state of unstable equilibrium and would be liable to turn over, were it not for the air tanks, which by means of the gearing are still kept at the water level. By this arrangement, if the dock endeavour to heel over, it is at once restrained by the air tanks, as it cannot change its perpendicular position without drawing those on one side partially into the water, and raising the opposite ones an equal amount out of the water. Thus if due precautions as to bulkheads be taken in the construction of the dock, to prevent an excessive force from being applied to turn the dock over, the side air tanks are sufficient not merely for determining the point to which the dock shall sink, but also for giving it stability both in rising and in sinking. These sectional docks have been connected with a system of railways, so that a vessel might be run off the dock on to the rails and be repaired there, while the dock was used to lift another vessel.

The Balance Dock or Box Dock, introduced in the United States in 1839, is shown in Fig. 18, Plate 19, and consists essentially of a pontoon bottom with two side walls. The pontoon possesses sufficient displacement to carry the whole weight of the dock and of any ordinary vessel that has to be raised. The side walls are hollow and of considerable width, serving the same purpose as the air tanks in the sectional dock, namely to prevent the dock from sinking too far and to preserve its stability in rising and sinking. Port holes are made in these walls to assist ventilation, and the walls afford the means of shoring up the ship by breast shores as in a stone dock; on the top are the enginehouse and pumps and the working platform. For lifting the heaviest vessel that could be taken inside the dock, gates have been fitted at the ends of the dock, so that it might float with the surface of the pontoon below the water and thus acquire an additional amount of buoyant power according to the depth of immersion.

Several balance docks have been constructed in America, which the writer believes have all been built of wood. The dock at Havana was built at New Orleans in 1858, and was towed out without accident to Havana. It is 300 feet long by 79 feet broad, and the hollow floor is 9 feet 6 inches deep; it can lift a vessel of 20 feet draft. It is provided with one steam engine, having a cylinder 12 ins. diameter and 30 ins. stroke, working with 60 lbs. steam, and driving seven pumps with barrels 24 ins. diameter and 30 ins. stroke, making about 14 double strokes per minute. Being constructed of wood, with a solid thickness of 2 ft. 6 ins. of timber in the flooring, the floating power of this dock is so great, that for sinking it not only has all the available space to be filled with water, but 500 tons of ballast have to be added. The total cost of this dock was £100,000.

In 1859 the writer, in conjunction with Messrs. Miers and Maylor of Rio de Janeiro, designed for the Brazilian government a plan of Floating Lift which combined the principles of the American hydraulic lift and of the floating dock. This is shown in Fig. 19, Plate 19, and consisted of two parallel floating pontoons A, carrying between them a framing B, on which the ship was to be lifted by chains, pulleys, traction bars, and hydraulic presses C, precisely as in the American arrangement. Two presses however were here applied to each traction bar, one at the further end and one half-way, whereby the strains on the traction bars, and therefore their requisite sectional area, were diminished; and the presses were so arranged that they made the lift in two strokes of half the length. The pontoons were arranged to separate into parts, when required for shorter vessels at different places; but when these parts were used combined together for the largest ships, means were provided to ensure the preservation of the full strength of the pontoons as girders.

In considering the essential principles of a good Floating Dock, and the defects most important to be guarded against, the first and principal requirement appears to the writer to be that the ship should be supported on as rigid a bottom as when on a building slip or in a stone dry-dock. This condition however is not universally recognised, and on the contrary it is urged that, if a vessel has assumed a certain distorted form in the water, this form ought to be retained when out of the water for the purposes of repair; and it is alleged that this can be accomplished by giving the ship an elastic bearing, such as that afforded by the separate portions of the sectional dock, or by the somewhat yielding saucer of the Thames graving dock. The employment of an elastic bearing appears to the writer however to be erroneous, because it is based on the assumption, either that the ship having already gone out of shape to a certain extent will not yield further; or that all the parts of a vessel are of equal weight per foot run, so that the elastic bearing will yield to an equal extent at all parts throughout the entire length of the vessel, which is evidently contrary to fact.

The other requirements of a floating dock are,—stability—ventilation—facility for repair of the dock itself—and a minimum expenditure of power and time in lifting the dock. The materials employed should also be arranged in such a manner as to obtain a maximum of strength from a minimum of material; and the design should be one admitting of many repetitions of a few forms, so as to allow of the work being done to a few standard templates, avoiding as far as possible any necessity for welding heats and smith's work.

As regards the question of stability, the difficulty is experienced not when the dock is raised with the surface of its floor fairly above the water, but during the time that it is in the act of raising or lowering a vessel. The stability of the dock when raised is great, as illustrated by Fig. 20, Plate 19, where A represents the centre of gravity of the dock with the vessel, B the centre of buoyancy when the dock is not heeled over, and C the new centre of buoyancy when the dock is heeled over. It will be seen that the new centre C is far outside the perpendicular from A, and that there is therefore a strong tendency for the dock to right itself. But when the dock has been sunk so that the bottom is entirely below the water line, then some contrivance must be resorted to not merely for keeping it from sinking to the bottom of the sea but also for keeping it from turning over.

When the vessel in the dock is equally loaded on each side of its centre line, and is placed on the keel blocks perfectly in the centre of the dock, then during the raising of the dock the whole is free from any tendency to turn over to one side more than the other, but at the same time is manifestly in a state of unstable equilibrium. Now if the dock heel-over a little under any influence, such as the wind, the causes which would increase its inclination and turn it over are, first, the fact of the centre of gravity of the ship and dock being no longer over the centre of support; and secondly and largely, the fact that the water remaining not yet pumped out shifts its position in the dock, and thereby seriously affects the stability, unless proper arrangements be made for preventing such an occurrence. In some docks that have been constructed due attention appears not to have been paid to this point, and the writer believes it is principally from this cause that failures have occurred in floating docks.

If a floating dock made without any longitudinal water-tight bulkheads, as in Fig. 21, were half full of water, and were to be heeled-over sideways so that the surface of the water should extend as a diagonal from corner to corner, the result would be to shift the centre of gravity of the water to A, one-third the width of the dock from the lower side or one-sixth from the middle. But if the dock have one longitudinal water-tight bulkhead along the centre, as in Fig. 22, then the same amount of heeling-over will cause the surface of the water to assume the shape shown in each compartment, which may be looked on as being divided into two equal parts, a parallelogram and a triangle. The centre of gravity of the two parallelograms B C D E will of course be the same as before the dock was heeled over, while the centres A A of the triangles being one-sixth of the total width from their lower ends, the common centre of gravity G of the two will be at one-twelfth of the width from the centre of the dock, or only half the distance of the centre of gravity in the former case; but as the contents of the two triangles taken together are equal to only half the triangle in the former case, the effective moment tending to turn the dock over is only 1-4th of that which it was without a bulkhead. Similarly if three bulkheads were put in, so as to divide the dock into four compartments, the effect of the water in turning the dock over would be reduced to 1-16th of what it was when there was no bulkhead; and generally, the tendency of the water to turn the dock over when it is at all inclined diminishes in the ratio of the squares of the number of chambers into which the dock is divided.

The foregoing principles were kept in view by the writer on the occasion of having to design a Floating Dock for the Danish Island of St. Thomas, in the West Indies. This dock has been prepared in England, and is now in course of erection at St. Thomas; and it is shown in Figs. 24 and 25, Plates 20 and 21. The leading particulars are as follows: length 300 ft., external width 100 ft., clear width between the side girders 72 ft., depth of bottom 9 ft. 9 ins., extreme height 42 ft. 3 ins. The dock can take in and lift, leaving an adequate amount of free board, a vessel drawing 24 ft. of water and not exceeding 4000 tons of actual weight, not tonnage; and the weight of the dock, with machinery and all complete, is about 3400 tons.

A A are the main longitudinal girders, and B the separate transverse water-tight pontoons, six in number, forming the bottom of the dock. These have "set downs" at the ends, where they receive the bottoms of the main side girders, as shown in Fig. 25; and as any one pontoon may have either to support the girders or to be partially supported by them, the connection has been made by means of very strong attachments rivetted to the pontoons and having shanks extending down to the very bottom of them. Cross plates are placed over the diagonals of the main girders, near the junction of the diagonals with the uprights; and on these plates bear strong cotters, so that if one of the pontoons were quite full of water it could be lifted by the others without the least injury. This attachment of the pontoons to the girders is one which can at any time be readily undone, so that any pontoon can be detached and floated away, and then taken up on the remaining pontoons for examination and repair.

The ship is supported in the usual way upon the keel blocks C, which are provided with folding wedges. These blocks are secured to the upper decks of the pontoons immediately over the longitudinal bulkhead D, which extends along the centre line of the dock in each pontoon. In this way a portion of the weight of the ship is transmitted directly to the bottom plates, say over the area E F. Another portion of the weight is transmitted by the two sloping ties I of the athwartship trusses to the water-tight bulkheads J, and by these to the bottom plates, which take off a further portion represented by the spaces F G. A further portion is transmitted through the ties K to the uprights L, and thence to the bottom at G H, and so on to the end. There are nineteen of the athwartship trusses above described, placed side by side in each pontoon; and at the point M is provided a system of fore-and-aft trussing, whereby the whole of these athwartship trusses are connected with the fastenings by which the pontoons are hung up to the main girders A A. In this way the weight of that part of the ship which bears on any pontoon is upheld either entirely by that pontoon alone, or by transmission of the surplus weight through the main girders to some more lightly loaded pontoon; and in order to enable any lightly loaded pontoon to receive the load brought upon it by the girders, each pontoon is provided with a reverse set of diagonals in the athwartship trusses, which transmit the weight from the sides towards the centre.

The bilges of the ship are supported by the hinged bilge-shores N N, which are provided with soft wood caps and wedges to take the immediate bearing against the ship, and are upheld by pauls of two different lengths, so that when the range of the shorter pauls is passed the longer pauls come into play. These pauls take into rack plates, which are supported on transverse timbers. The pressure produced by the bilge-shores is transmitted mainly to the longitudinal water-tight bulkheads J in the pontoons. This system of bilge-shores was proposed by Messrs. Miers and Maylor in the Brazilian hydraulic dock before referred to.

When the dock is fully up with the ship on it, the pressure from the water is comparatively trifling, being not more than about 9 feet head of water against the bottom plates; but when the dock, after being sunk to its full depth and having received the ship, is in the act of beginning to rise by the water being pumped out, then the pressure of the external water upon the bottom plates of the sunken portion is about 28 feet head of water or about 12½ lbs. per square inch or 4-5ths ton per square foot. In order to economise material, the writer determined on resisting this pressure, not by means of "frames," as in a ship, because for so large an extent of surface their weight would have been excessive; but by means of a system of inverted queen trusses O O. As regards the vertical plates, forming the sides and ends of the pontoons, these trusses are in most cases complete; but as regards the top and bottom plates and a few of the vertical plates, advantage is taken of the various diagonals of the main trusses to form portions of these minor trusses so far as they extend. This arrangement does not require one piece of metal to fulfil two duties at a time, inasmuch as when the main trusses are fully loaded, by the dock being fully raised and carrying the whole weight of the vessel, the pressure produced by the water is then but slight, and therefore the small trusses come upon the main trusses for only an inconsiderable amount of assistance; whilst when the dock is sunk and the full strain comes upon the small trusses by the pressure of the water, the main trusses are not then required to exert any resistance in respect of the vessel, which at that time is borne by the water.

The bottom members of each of the main girders A A are formed not only to resist extension, but are provided with sufficient lateral stiffness for resisting compression, by being composed of two parallel double girders P P, connected at the bottom by horizontal struts and diagonal ties. The top member of each main girder is composed of two small girders Q Q, similar to those of the bottom member but united at their lower edges by a floor R forming a trough section. This trough has its sides and bottom made water-tight, and is covered with a wooden deck carried on iron deck-beams; and within it are the various shafts and gearing for the working of the dock. The diagonals of the main girders A A are formed each of two plates, connected by stretchers, bolts, and lattice bracing. The uprights of the girders are made of open lattice columns with strong angle-irons at the corners; and to these angle-irons are rivetted plates and other angle-irons, which act as guides for the floats T. From each of the uprights and from the junction of the diagonals extend the main altar frames S S to the top of the pontoons; and between each pair of these main frames are intermediate lighter altar frames. The feet of all the altar frames are secured to the pontoons by being placed within angle-iron wedging pieces, and by being bolted to the pontoons. This arrangement is adopted to admit of any pontoon being disconnected from its altar frames, when that pontoon requires to be docked for repair. The upper slopes of the altar frames are provided with steps, which receive the wood blocking for the purpose of applying shores to the ship when necessary, and also to afford support for the gangway boards which extend longitudinally from altar to altar. The risers or spaces between these boards are left open, so as not to interfere with the ventilation.

There are in all twelve floats T, one to each of the bays of the two main girders A A; each float is 46 ft. 9 ins. long, 11 ft. 3 ins. wide, and 5 ft. deep. A longitudinal central web extends from end to end of each float, worked out in three places to form boxes for receiving the tubes of the nuts through which pass the three regulating screws U. The floats are made with angle-iron "frames" placed transversely at frequent intervals, and every second frame has diagonal ties added which transmit the upward strain to the central web and thence to the screws. Immediately opposite each screw there is a transverse truss having double diagonals, to take the weight of the float when lifted for repairs at any time while the dock is above water. The exterior of the dock is protected by wooden waling pieces and fenders.

It was the original intention to deck over the pontoons with a wooden deck laid with $\frac{1}{2}$ inch spaces upon beams placed on the tops of the pontoons; but fears were entertained that during the repairs of iron steamers this deck might be set on fire. The wood deck was therefore abandoned, and a Portland cement deck 3 ins. thick was decided on; but experience has shown that this is not necessary, and that a coating of cement and tar $\frac{1}{2}$ inch thick is all that is required for protecting the tops of the pontoons. Portland cement however has been used in the interior of the pontoons, to fill up all confined places where decay might arise.

The deck on the top of the main girders A A of the dock is widened by brackets for a length of 100 feet at the centre, and on this part are erected the enginehouses W W with workshops at the ends. Each enginehouse contains a boiler of locomotive construction, having a firegrate 3 ft. 4 ins. square, and a barrel 3 ft. 6 ins. diameter and 7 ft. 6 ins. long, containing 110 tubes 2 ins. diameter. The boilers are fed by injectors with fresh water carried in tanks made in the top of the girders. A wrought-iron well is also provided to each enginehouse, which hangs down between the central uprights of the main girders and contains a feed pump to draw water from the sea whenever required. Each boiler supplies steam to a pair of inverted direct-acting engines, having cylinders of 10 inches diameter by 15 inches stroke, working the pumps through the line shafts V V which extend along each side of the dock. The pumps are placed inside the uprights of the main girders, in the spaces between the ends of the floats T. At the centre upright there are two pumps, one of which pumps out the pontoon to the left and the other that to the right. In each of the next two uprights on either side there is one pump connected respectively with the second pontoon and the third or end pontoon. The pumps are 17 inches bore, and the stroke can be varied from 12 inches to 24 inches by altering the position of the crank-pin in the disc driving each pump. The linings, buckets, and suction-valve seats are of gunmetal, and there are doors by which the valves and buckets can be examined or removed when the dock is raised; means are also provided for drawing up the bucket and valve when the dock is sunk, or for sending down another valve on the top of the first without removing it; or the lateral outlets through which the pumps discharge can be closed, and the bucket being withdrawn a workman can descend to the suction valve itself. Each pump is provided with a pipe between the clack and the bucket, by which air can be admitted, so as to stop or check the action of any one pump out of each set of three, the admission of the air being governed by a cock. A float in each end of every pontoon indicates the quantity of water in the pontoon; and the tubes through which the float-rods pass up serve as air tubes to the pontoons.

Two small direct-acting inverted engines are also placed in each enginehouse, fitted with link motions and driving by gearing the shafts X X, which extend right and left along the top of the dock to work the regulating screws U, of which there are three to each float T. These screws are 6 inches diameter and 1½ inch pitch; their bottom ends are formed with collars like the thrust bearings of a propeller shaft, and cased with gunmetal; they are supported in steps fitted with bearing surfaces made of discs of lignum vitæ. The screws work in cast-iron nuts, which are contained in deep cast-iron tubes fixed to the floats. The spaces in the tubes above and below the nuts are filled up solid with tallow. As the screws make only 200 revolutions during the whole ascent or descent of the dock, the speed of the engines has to be greatly reduced by the gearing; it can however be varied at pleasure, so as to allow for greater rapidity in the descent than in rising.

On each side of the dock a screw-cock inlet-valve is provided on every pontoon, to admit the water for sinking the dock. These valves are worked in four separate sets of three each, by handwheels in the enginehouses, gearing with the shafts Y Y extending along the top of the dock. In each enginehouse there are two tell-tales, to show the fore-and-aft and the athwartship level of the dock; each consists of an index magnifying by means of gearing the angular movement of a pendulum. Speaking tubes extend from one enginehouse to the other, and also from each enginehouse to the bridge at the end of the dock, from which the orders are given; this bridge is closed, as shown in Fig. 24, except when the very longest ships are taken in.

The mooring of the dock is made from a single mooring anchor placed to windward, to which is secured a chain of 35 fathoms length, made of flat links of the form employed in suspension bridges, with the eyes rolled in the solid. To this chain are attached two smaller chains, each 35 fathoms long, which are made fast to the mooring rings on the head or windward end of the dock. At the stern end there are two small mooring chains, led away at an angle to two mooring anchors; these chains pass over rollers up to capstans at the top of the side girders, by which they can be hauled in as required. There is a one ton crane on each of the four quarters of the dock, for raising or lowering material, &c.

From the foregoing description it will be seen that, for the purposes of working, the dock may be considered as divided into four independent sections; for in each of the two enginehouses the engineer has the power of working independently the set of three pumps on the right and the set on the left; and the same with regard to the floats and the inlet valves. In order to lower the dock for receiving a ship, the inlet valves are all opened to admit the water into the ends of the pontoons as far as the water-tight bulkheads J; the central portion never requires to be filled, inasmuch as the whole buoyancy of the dock can be overcome by the admission of water into the side compartments. While the dock is sinking, the engines working the regulating screws U are put to work at such a speed as to keep the floats T always one half immersed in the water. When the dock is sunk to the required depth, the inlet valves are shut, and the ship, which has been moored close to the dock moorings and therefore directly to the windward of the dock, is hauled in over the keel blocks and adjusted by means of breast tackles and shores. The pumping engines are then put to work, and the dock is raised until the keel blocks just take their bearing against the vessel; and the bilge shores being hauled taut so as to secure the vessel thoroughly, the pumping is resumed, and the screw engines are put to work at their slow speed, so that as the dock rises the floats are still maintained just about half immersed. In Fig. 25 the float T on the left-hand side is shown raised into an intermediate position, which is the position it would occupy when the dock is rather more than half raised: when the dock is fully up, the float is in its lowest relative position, having its bottom level with the underside of the girders P P, which form the bottom member of the main girders A A; and when the dock is sunk to the extremity of its range, the top of the float is up against the underside of the girders Q Q, which form the top member of the main girders A A.

In a properly constructed dock it is difficult to see what influence could force the dock out of level under any circumstances; but supposing it were ever found that, in the raising of the dock now described, one corner was becoming low and the opposite corner high, this would immediately be corrected by altering the working of the screw engines, so as to depress the three floats at the low corner, and elevate those at the high corner. This alone would always be sufficient to adjust the dock, without interfering with the pumping, which might go on continuously; but there is in addition the power of throwing any three of the pumps out of gear while keeping the others at work, and the inlet valves of the high corner might even be opened to let the water in again, if this were desirable in an extreme case.

In designing the construction of Floating Dock that has now been described, the object of the writer was to supersede the objections that appear to him to attach to the Morton slip and other ship lifts, and also to the two principal of the previous floating docks, namely the Balance dock shown in Fig. 18, and the Sectional dock shown in Fig. 16. The reason for discarding the use of slips and lifts was that they are dependent on the earth for their support. This objection however did not apply to the sectional or the balance dock, both of which, like the St. Thomas dock, have the important advantage of being wholly independent of the land, and are therefore capable of use in any place where there is sufficient shelter and depth of water, combined with the means of mooring. The grave objection in the writer's opinion to the sectional dock is its entire want of rigidity. Although this does not apply to the balance dock, yet this dock also involves objections which the writer believes to be of importance. One is that, as ordinarily built in one entire structure, the balance dock requires either an excavation into which water can be admitted to float the dock after its completion, or else the construction of very large and expensive launching ways. Moreover the rigidity and also the stability are obtained by the use of complete side walls, which have a large displacement when the dock is sunk. As far as the question of rigidity is concerned, the writer believes that these side walls involve the use of more iron than is required in an open girder to obtain the same strength; while they absolutely preclude efficient ventilation at the sides of the ship, and present a large extent of surface for reflecting the heat of the sun and for the wind to act upon. The engine power for pumping out the water is also increased as compared with open sides by the greater displacement of the solid sides when sunk, which involves a corresponding increase in the quantity of water to be taken in and subsequently pumped out.

In the St. Thomas Dock, although the lower part is composed of six separate pontoons, for facility both of original construction and of subsequent examination and repair, the objection applying to the sectional dock is got over by the use of the strong side girders. These are provided with a double set of diagonals, and have their top and bottom members made of such strength as to be capable of resisting a strain tending to depress either the middle or the ends. Thus supposing the dock is in the act of raising a paddle-wheel steamer, which has a large portion of its weight accumulated in the centre, and only a small portion at the ends, the girders will transmit the surplus floating power of the end pontoons to the assistance of the heavily loaded central pontoons; and in the event of two small but heavy vessels being taken on at the ends of the dock, the girders will convey the extra flotation of the central pontoons to those at the extremities of the dock.

As regards the important question of stability and the means of controlling it, it is to be observed that even with the balance dock shown in Fig. 18 there is nothing to fear so long as the upper surface of the bottom is fairly above the water, because on any attempt at heeling-over, the rectangular bottom produces a change in the position of the centre of buoyancy so rapid compared with any slight inclination of the dock that the tendency to right itself is very strong indeed. Moreover at that time the dock is pumped dry, and the danger arising from shifting the centre of gravity of the internal water is at an end. In Fig. 23, Plate 19, taking A B as the water line, the balance dock is shown fully raised and heeled-over; and the power of restoring an upright position to the dock under these circumstances has already been fully investigated in reference to Fig. 20. But when the dock while in the act of being raised or lowered has its floor wholly immersed, as shown by the water line C D, then the tendency to restore equilibrium is not so great, as the effect of the whole triangle E F G is diminished by that of the interior figure H I K L. Moreover there is at that time within the dock a large amount of water, the centre of gravity of which is of course shifted by the heeling-over; and the effect of this is most serious, unless a sufficient number of bulkheads be provided to subdivide it into small sections. From whatever cause however the stability of a balance dock may have been disturbed, it is clear that the effect of its sides to restore equilibrium can be increased only in proportion to the amount of heeling-over, and can never be caused to exert any effect in excess of this. If therefore a balance dock has once heeled-over, it cannot be righted by its sides, so long as the force which caused the heeling-over is continued.

With the side floats however in the St. Thomas dock the case is different, as the position of the floats in reference to the dock can be controlled as desired; and therefore in the case of any heeling-over an extra immersion can immediately be given to the floats on the low side, while those on the high side can at the same time be raised more out of the water. By this means when the heeling-over is only slight and therefore the tendency to heel-over further is also slight, the floats can be made to exert as great a counteracting power as the walls of the balance dock would have when the heeling-over was great and therefore the tendency to go further also proportionately increased.

Another important reason for preferring the open sides of the St. Thomas dock to the close sides of the balance dock was the saving of time in pumping for raising the dock. Supposing that the St. Thomas dock had been made with close sides, these would have had each a sectional area of 14 ft. wide by 25 ft. deep when fully immersed, which with 300 ft. length would give 210,000 cubic feet total displacement for the two sides. The section of the bottom is equal to 900 square ft., which with 300 ft. length gives 270,000 cubic feet, or 7700 tons; but as the dock with all its machinery complete weighs 3400 tons, only 4300 tons of water have to run in, equal to 150,500 cubic feet. Hence the close sides would have added 21-15ths to the amount of water to be pumped out; so that the time required for pumping out the dock if the box sides had been used would have been in the ratio of 36 to 15, or 12 to 5, as compared with the open sides.

In respect therefore to the three questions of ventilation, stability, and economy of pumping, the writer trusts that he has shown satisfactory reasons for preferring the open lattice girders with moveable floats to the close box side-walls of a balance dock.

Mr. R. Mallet remarked that the paper just read gave a clear account of the successive methods employed for docking vessels, and of the latest improvements that had been effected in the construction of floating docks. At the present time the use of floating docks was becoming more and more important at foreign stations as the number of iron steamers increased; and he thought they would to a great extent supersede the ordinary masonry docks, except for the purposes of extensive arsenals and large dockyards. In the St. Thomas floating dock described in the paper, the addition of the series of adjustable air-floats in the open sides of the dock appeared a most important improvement, affording the means of preserving the dock always truly level, by regulating the depth of immersion of the floats by means of the vertical screws. One of the principal difficulties attending the adoption of floating docks for foreign stations was the necessity of transporting them from the place of construction to their destination: if they were sent out in one piece, there was the danger attendant upon towing them across the open sea; while if sent in a number of separate pieces, there was the serious increase in expense for putting them together at a foreign station, often with imperfect appliances, and for launching them where there might not be sufficient shelter. If a floating dock could be contrived which should be furnished with the means of navigating itself out to its destination, he thought it would combine the two elements necessary to a complete commercial success; and a model was shown in the present International Exhibition of a floating dock furnished with screw propelling power and similar in external shape to a ship, obviously for the purpose of working itself out to its destination, and perhaps intended to retain its power of propulsion for future use while employed in docking ships. He enquired whether it would have been considered an advantage, in the case of the St. Thomas floating dock, to construct it so that it could be sent out from England complete without taking to pieces. Another interesting contrivance shown in the Exhibition for lifting ships was a steep slip, somewhat similar to the Morton slip described in the paper, but arranged with a considerable number of parallel chains for bringing up and launching a ship broadside on instead of endways; a slip on this plan had been constructed by Messrs. Labat at Bordeaux, and had been in actual use for several years, and by this means vessels could be taken up or lowered down at a single tide.

Mr. **Bramwell** believed that the plan of drawing vessels up a slip broadside on instead of endways was originally suggested by Mr. Scott Russell, but he was not aware of its being carried out in practice. With regard to the question of conveying a floating dock to its destination, the floating dock at Havana was towed out from New Orleans without accident, as mentioned in the paper; but on the other hand, in the case of towing out a floating dock in the

Adriatic to the Austrian port of Pola, the towing ship was lost in a storm, and the dock itself was cast ashore, but was not injured. It was therefore a question to be decided for each particular case, whether it was preferable to put the dock together beforehand and incur the risk of towing it out complete to its destination, or to send it out in separate pieces to be put together on the spot at possibly a somewhat greater cost. The floating dock that had been referred to as fitted with the means of propulsion, of which a model was shown in the Exhibition, was not intended he imagined to navigate itself across the open sea to its destination; but he thought the propelling power was more probably provided only for enabling the dock to shift its position with facility through short distances at the station where it was employed. A floating dock now being constructed at North Woolwich for the Bermudas was also being provided with power for propelling itself.

Mr. R. W. Thomson remarked that with regard to the advantage of sending out a floating dock in pieces, to be put together at its destination, it should be borne in mind that all work which required only rivetting could easily be put together at any foreign station at a cost not much exceeding the sum paid for the same amount of rivetting in this country; and it was only when smiths' work was required that the expense of erecting abroad would be seriously increased. Having had to design a floating dock for Java in 1859, which was constructed by Messrs. Randolph and Elder of Glasgow, he had arranged all the plates of the sides and bottom to be precisely alike in every respect, and the rivet holes were all punched accurately to templates, so that any of the plates would go together indiscriminately with perfect accuracy; and the same principle was carried out as far as practicable in the construction of the girders and other portions of the dock. The result had been that the whole of the work went together with the greatest facility, and the cost of erecting was also extremely moderate, the whole cost of the entire work being very much less than could have been the case if the dock had been made to take itself out to its destination. He had had the opportunity of seeing this dock put together abroad, and had never seen anything of the kind in boiler work which went together with less trouble; and he therefore considered it was more economical and satisfactory to send out a floating dock to a foreign station in pieces than in any other way. The difficulty of launching appeared to him to be somewhat overrated, because a construction of that character he considered would not draw more than from 2½ to 4 feet of water; and by erecting it in a small basin excavated to just that depth below high-water level, the dock was readily floated out when the fore-shore of the basin was removed. By this method the dock already mentioned had been successfully floated at Surabaya in Java, although it had unfortunately been lost subsequently through carelessness in sinking it before the sides had been caulked completely water-tight. Two more floating docks had been constructed at the same works on substantially the same plan, one of which was now in use at Callao in Peru, and the other at Saingon in Cochin China; and no portion of these was put together at home.

Mr. W. CLAY remarked that he had lately seen at Copenhagen a floating dock in which the water was driven out of the pontoons by the pressure of air forced in by an air-compressing pump, instead of pumping the water out in the usual manner, the object being to save power by avoiding having to pump the water up to any greater height than necessary, as the dock gradually rose out of the water; and he understood that this mode of working the dock was very successful in practice.

Mr. C. W. SIEMENS observed that the plan of raising a floating dock by forcing in compressed air to expel the water did no doubt possess the advantage pointed out, that it avoided raising the water to a greater height than the external level; but in practice he thought there was not really any saving of power by this plan, because in the ordinary plan of pumping the water out each gallon of displacement in pumping represented exactly one gallon of water pumped out; whereas in employing compressed air it would be necessary to force in more than a gallon of air of atmospheric pressure for each gallon of water expelled, according to the depth of immersion of the dock; that is, supposing the diameter of the pump and number of strokes to be the same in both cases, a longer stroke would be required for compressing and forcing in the air than for simply pumping out the same bulk of water. Moreover in the employment of compressed air in the manner described, he was not fully satisfied that the action would be uniform in expelling the water and raising the dock; it would have to be ascertained by practical trial whether the accumulation of compressed air in the pontoons would not give rise to an uneven and spontaneous action in expelling a large volume of water through expansion, when a reduction in the resisting head of water had once taken place.

In the St. Thomas dock described in the paper he fully concurred in the advantage of the regulating air-floats for adjusting the level of the dock in rising or sinking; and he enquired whether there would be any liability of the dock heeling over towards either side, in case it ever happened to rise or sink more rapidly than the floats could be adjusted in height by means of the regulating screws. In the instance of a large floating dock which he had seen constructing at Carthagena in Spain two years ago, he had observed that an expensive masonry dock was also being constructed, which he understood was intended to contain the floating dock; and he did not see what was the object of building the masonry dock as well as the floating dock, since it appeared the St. Thomas floating dock and others described in the paper were constructed for use in open harbour.

Mr. **Bramwell** was not aware of the reason for building a masonry dock to contain the floating dock at Carthagena, unless it was intended simply as a guide for the floating dock in sinking and rising, the masonry dock being without a gate, and in that respect differing from an ordinary dry dock. The same was the case also in regard to some of the American sectional floating docks, which had stone chambers constructed to contain them; but if a floating dock were so built as to be really serviceable for the purposes of a floating dock, he was at a loss to understand the desirability of constructing in addition a masonry dock to receive it.

With regard to the plan of expelling the water from the pontoons of the floating dock by forcing air in, he had been much inclined to adopt that method for the St. Thomas dock; but he had feared the possibility of some such accidental mishap as had been alluded to, from the dock being brought up with a rush by any sudden liberation of the compressed air forced in; and he had therefore preferred to adhere to what appeared the safer plan, namely to pump the water out. In the event however of constructing any other floating dock like that for St. Thomas, he should certainly go into that question fully, and make a point of seeing the Copenhagen dock at work, in order to ascertain the real results of the experience in that instance. One objection to pumping the water out of the pontoons for raising the dock was that this produced of course a tendency of the hollow pontoons to collapse under the external pressure, and they had to be properly strengthened to resist that pressure; whereas in injecting air to expel the water this difficulty was got rid of, as the internal pressure of the air was at least equal to the external water pressure. On the other hand a much better class of workmanship was required in the pumps for dealing with air than for pumping water; and much more work was thrown upon the pumps in injecting air, as they had first to compress the air to the required pressure before they could force it into the water chambers of the pontoons.

In reference to the working of the adjustable air-floats in the St. Thomas dock, it would not be possible for the dock ever to sink more rapidly than the floats were allowed to rise, because the floats when only half immersed had buoyancy sufficient to sustain the dock when the water chambers of the bottom pontoons were full of water; and in rising, if the floats were prevented by any accident from descending rapidly enough, the rate of pumping out the water could be reduced to as slow a speed as desired, or the inlet-valves could be opened again to re-admit the water to the pontoons on either side of the dock. By these arrangements ample provision was made against any possibility of the dock heeling over either in rising or in sinking.

Mr. R. **Mallet** enquired whether the water pumped out of the pontoons was discharged by the pumps always at the same level.

Mr. **Bramwell** replied that the discharge orifices of the pumps were situated at only 5 feet height above the top of the pontoons forming the bottom of the dock, so that during the greater portion of the time of raising the dock these orifices were under water, and therefore the water pumped out was not lifted unnecessarily above the level of the external water; and it was only when the dock was almost fully raised that these orifices came above the external water level, and even then the height of lift for discharging the water was so small as to be practically unimportant.

From the particulars given in the paper of the previous constructions of floating docks, it would be evident that there had not been much room for introducing any entirely new features in the St. Thomas dock; and in designing the construction that had been described his endeavour had been, not so much to do something that had not been done before, as to combine the advantages that were offered by the principal plans previously employed, while at the same time avoiding the objections which he conceived to attach to each. He had thus combined the open sides and repetition of similar parts which characterised the American sectional dock, with the rigidity which constituted the important superiority of the box dock; thereby avoiding the objections of the flexibility of the former, and the want of ventilation of the latter, together with the want of sufficient power for controlling the dock in rising or sinking. The harbour of St. Thomas was the principal depot for the West Indian mail steamers, but as there had hitherto been no dock at that station large enough to receive these vessels, they had been obliged to go for repairs to the box floating dock at Havana; this dock was found troublesome in working from the difficulty of keeping it level in rising, so that it was apt to go sideways in the water, requiring the pumping to be stopped and the water to be re-admitted into the dock, which involved much delay in the operation of raising a ship for repairs. By the open sides of the St. Thomas dock however, not only was good ventilation ensured, but all the time and labour were saved that were required in the box dock for pumping out the large quantity of water contained in the closed box-sides.

With regard to the importance of making the several parts to fit together in erection with the greatest facility, he had kept this object in view in the design of the St. Thomas dock, in which the plates of the bottom pontoons were made exact repetitions of the same patt so as to go together indiscriminately, and consequently no difficulty whatever had been experienced in the erection. At the same time great care had been taken to avoid any necessity for smiths' work in the operation of erecting the dock at its destination, and everything had been done to get plain rectilinear work alone. The putting together at St. Thomas had been commenced on 24th April last, and the dock would probably be completed ready for work in about two months from the present time, making about three months for the entire erecting.

The PRESIDENT remarked that the paper which had been read gave a very complete idea of the gradual development of this important branch of engineering; and he moved a vote of thanks to Mr. Bramwell for his paper, which was passed.

The Meeting was then adjourned to the following day.

The Adjourned Meeting of the Members was held in the Lecture Theatre of the Conservatoire Impérial des Arts et Métiers, Paris, on Wednesday, 5th June, 1867; JOHN PENN, Esq., President, in the Chair.

The following paper, by M. Tresca, Engineer Sub-Director of the Conservatoire Impérial des Arts et Métiers, was read:—

ON THE "FLOW OF SOLIDS," WITH THE PRACTICAL APPLICATION IN FORGINGS, &c.

By M. TRESCA.

It is now some years since a numerous series of experiments were made by the writer on the change of form of solid bodies under the action of powerful pressure, which have led to characterising the general results thus obtained by the title of the "Flow of Solids." The first paper relating to this subject was read by the writer before the Academy of Sciences at Paris, in November, 1865; and the views then advanced have been continuously corroborated by the results of a great variety of further experiments made by the writer. The question now includes consequences of great diversity; and the special object of the present paper is to make known the most salient facts required for explaining some important practical applications, upon which this theory appears to the writer likely to throw new light, such as the rolling, forging, punching, and planing of metals.

Principle of the Flow of Solids.—If a hollow cylinder closed at the bottom end have a solid cylindrical block of lead placed inside it, fitting it, and the hollow cylinder have a round hole in the centre of the bottom, a powerful pressure on the top of the solid block of lead will produce a cylindrical jet of metal, having a sectional area equal to the hole in the bottom of the cylinder. For arriving at this first result the writer used the apparatus represented in Fig. 1, Plate 22, where A is a cast-iron cylinder 3·94 inches diameter, closed at the lower end by a cover B securely bolted to the corresponding flange. In the cover is drilled a round hole 1·97 inch diameter, and the shoulder left in the interior of the cylinder supports the moveable die C, containing the central orifice which is to serve for the jet. The block of lead to be acted upon, being placed in the cylinder at D, is covered with the steel piston E; and the whole being placed in a hydraulic press, and a sufficiently powerful pressure exerted on the head of the piston E, a cylindrical jet of metal J is forced to flow through the hole in the die C.

In most of the experiments the block of lead operated upon consisted of a series of superposed plates or discs of uniform thickness; and this allowed the means of determining the change of form and exact displacement of each of the individual layers in the entire mass, by making a longitudinal section of the resulting jet at the completion of the experiment. In Figs. 5 and 6, Plate 23, are shown longitudinal and transverse sections, two-thirds full size, of the cylindrical jet produced from ten discs of lead, each 0·12 inch thick and 3·94 inches diameter, forced to flow through a concentric circular orifice of 1·18 inch diameter in the die C. The uppermost dotted line D D indicates the original height of the block of lead; and the pressure has been continued in this instance until the jet of 1·18 inch diameter has attained a length of 7·87 inches.

The change of form produced in the interior of the mass is characterised by the following circumstances:—

First, in the original block the parallel faces of the different discs remain flat, or sensibly so, over all that portion of their surface which is situated outside an imaginary prolongation backwards of the central jet.

Secondly, within the area of this backward prolongation of the jet all the layers bend over so as to flow into the jet simultaneously, as though they individually followed a general current directed towards the orifice.

Thirdly, the external surface of the jet itself is composed entirely of a single cylindrical envelope formed out of the bottom disc of the original block.

Fourthly, each of the original layers forms in the jet a distinct tube, concentric with the jet, and occupying in the jet a concentric position between the tubes thus formed by the other layers, as seen in the transverse section, Fig. 6.

Fifthly, each of these tubes is closed at the outer extremity by a cap more or less convex, as seen in Fig. 5, which is formed out of the central portion of each of the original discs.

The same results having been obtained by the writer with various other metals—such as tin, silver, copper, aluminium, iron, and even steel, as also with different kinds of potter's clay, sand, powdered sugar, and small shot—the general conclusion has been arrived at that the particles of solid bodies when subjected to a sufficient pressure flow in the same way as liquids; and as the resulting jets from each experiment remain in a permanent state, these have allowed of establishing the fact that the flow of the different strata of the cylindrical mass under the same conditions produces in each case a tubular and concentric form of jet similar to that shown in Figs. 5 and 6.

When the cylindrical block experimented upon has only a small height relatively to the diameter of the orifice, the material becomes displaced in the same way as a thin sheet of liquid at the edge of a circular aperture. This fact explains the suction produced in the Catalan blowing engines; and it is seen by the specimens obtained under these conditions, especially by the two represented in Figs. 7 and 8, Plate 24, that the central cavities assume a perfectly geometrical form. In each of these cases the orifice in the die C was 1·58 inch diameter, and the original height of the block is indicated by the uppermost dotted line D D, the original thickness of each disc being 0·12 inch. It is also seen that, when the formation of these cavities takes place, the diameter of the jet is no longer equal to the full diameter of the orifice; the formation of a *contracted vein* is manifest, and a new analogy is thus obtained between the flow of solids and liquids.

The series of these experiments made by the writer have been of very great variety and extent; but those only will be referred to in the present paper that are the most characteristic, and the specimens relating to these will be exhibited and described.

1st. A jet was formed by the use of two half cylinders of lead, fitted close together, so as to form one complete cylinder divided longitudinally. The object of this experiment was to make sure that the want of adherence of the discs previously tried had not had a preponderating influence on the results of the flow. The two half cylinders, each perfectly solid, were made to flow simultaneously in the same apparatus as before; and the jet on being separated after the flow in the line of the longitudinal joint showed the same arrangement of concentric flow. The only difference was that the several layers were marked in another way, principally by the wrinkles and small irregularities of the surface of the joint, which however remained on the whole practically flat. The relative motions of the particles are represented by a few undulations, which exactly correspond with those that would be expected in the flow of a similar liquid vein.

2nd. A cylinder formed of two discs of iron, each 1·57 inch thick and 5·91 inches diameter, was heated to a red heat, but not so high as a welding heat. These discs were placed one upon the other in a cylindrical die, having at its base a hole 1·97 inch diameter, and were then compressed by a steam hammer weighing 12 tons. At the third blow the die broke, but the iron had already formed a jet of 2·56 inches length; and on making a longitudinal section of the whole, as shown in Fig. 30, Plate 30, it was found that, instead of only the single line of joint anticipated from the use of two discs, every one of the parallel layers in the iron plate of which each disc was formed had flowed independently, so as to produce a series of lines, in the same way as with the number of separate plates employed in the experiments with lead.

3rd. A jet was formed from a block of ten discs of lead of 1·97 inch diameter, forced through an orifice of only 0·12 inch diameter. The object in this experiment was to carry the process to the extreme, so as to obtain a regular thread composed of ten superposed envelopes. Here again the sample obtained shows the superposition of the concentric layers in the whole length of this thread, 23 feet; but the plates did not remain flat (as was expected from previous investigations) in that portion of the block which is situated outside the backward prolongation of the sides of the jet. Only the discs near the top and near the bottom now remained flat, while in the intermediate portions of the mass a more rapid flow took place from the circumference towards the centre, which hollowed each of the discs into the form of a funnel. This effect was most marked in the disc originally placed equidistant from the two ends of the cylindrical block. Similar results are obtained when the block experimented upon, instead of being formed of superposed discs, is taken from the jets previously produced of 1·18 inch diameter. The concentric rings which then constitute the block continue cylindrical from the top down to a certain height above the orifice, but a little lower down they become drawn inwards, so as to enter the central orifice simultaneously, each taking the form of a funnel whose apex would fit into that of the larger funnel immediately below it. The manner in which this general displacement from the circumference to the centre is produced is clearly shown by the longitudinal sections made of these blocks after the experiment; and it is also seen that this lateral movement is limited to the lower parts of the block, whilst the upper portions go down parallel to one another and without any change of form, until they arrive at a certain level that must be considered as the point of limit of jet action, beyond which the influence of the orifice ceases to be perceptible. In other experiments a different position is obtained of this limit of jet action, which evidently depends on the diameter of the orifice and the action of the external forces.

4th. For the purpose of imitating the flow of a liquid with constant head through a concentric orifice, a smaller apparatus of 1·18 inch diameter was used; and such a number of discs were employed, each 0·12 inch thick, that by the descent of the piston through the thickness of one disc the top part of the mass should not be brought within the limit of jet action. The piston was then raised, and a single disc added upon the top of the mass; and this process being repeated a great number of times, jets of great length were produced, which may be considered as jets obtained with a constant head, since in reality the head never varied more than 0·12 inch, and this small variation was entirely beyond the limit of jet action. The jets formed were very regular, but the only special feature by which they are characterised is that the distances between the ends of the successive tubes are all equal to one another. In jets of any length, produced in this manner, the same character would always be preserved, and all the ends of the concentric capsules forming the jet would present identically the same arrangement.

Polygonal orifices and eccentric circular orifices have been successively used; and in both cases it was invariably found that the superposed discs which constituted the primitive block became transformed into a series of tubes fitting into one another, each disc producing a corresponding tube. The plan of subdividing the primitive block into a number of separate discs or layers has the advantage of affording the means of finding the actual displacement of each of the joining surfaces, by making sections of the jet afterwards; and thus each portion of the original mass can be traced in its passage, as in the case of the concentric circular orifice. With a polygonal orifice it has been discovered that the general displacement towards the centre of the orifice is always accompanied by a circular displacement, starting from the planes passing through the axis and through the centre of the sides of the orifice, and directed towards the planes which pass through the angles of the polygon. These torsional movements, which are rendered manifest in many ways, may certainly be referred to the same actions as the gyratory movements observed in the flow of liquids when the orifice is not placed symmetrically with respect to the sides of the vessel containing the liquid. On examining the surface of a block from which one of these polygonal or eccentric jets has been produced, the direction of the rectilinear or curved currents that take place even at the surface is clearly indicated by streaks of different shades. These currents are everywhere extremely regular, and the sections of all the jets show that the displacements are everywhere determined under absolutely geometrical conditions.

Amongst this class of experiments, special reference may be made to trials with double orifices, the results obtained in these cases being remarkably characteristic. The die having two circular orifices drilled in it, of the same diameter, and placed symmetrically with regard to the axis of the block, there are necessarily two planes of symmetry perpendicular to each other; and hence two perfectly equal jets might be expected to be produced, each consisting of a series of tubes arranged in the same manner. This however was not found to be the case, but one of the jets was much shorter than the other; and on taking the block out of the die, the small streaks visible on the upper surface of the block showed that at the end of the operation the general motion was directed from all points of the upper portion of the block towards the orifice which had produced the longer jet. On close examination of the die it was found that, although the two orifices were equal on the side next to the base of the block, only one of them was perfectly cylindrical, whilst the other was reduced in size by having been made slightly conical, and consequently the jet formed at this orifice was diminished 0·004 inch in diameter. An exceptional resistance was thus occasioned, which caused the displacement produced to be analogous to that observed in the case of a jet through a single eccentric orifice; for the currents in the block passed over the obstructed orifice almost as though no such orifice existed.

The conical hole having been carefully drilled again, it was expected that symmetry would then be obtained both in the block and the jets, as in other cases. Such was indeed found to be the result; but the tubes of the two jets, instead of being circular or polygonal, had now become oval, being flattened towards the plane passing through the axes of the two jets. This effect evidently arises from the fact of each tube being to a certain extent crushed inwards by the matter which has to find place round it, and which is more and more abundant towards the axis of the cylindrical block.

When the two circular orifices are of different sizes and their centres are in the same diameter line of the block, as in Fig. 9, Plate 25, the distribution of the material in the two jets produced takes place in the peculiar manner shown full size in the transverse sections, Figs. 10 to 15. In this experiment six discs of lead were employed of 3·94 inches diameter, and the two holes for the jets were 0·96 inch and 0·68 inch diameter. The material in the block partly follows two distinct currents directed towards the two orifices; but the result is not the same at different heights in the block. As soon as the pressure is sufficient, the lower layers begin to enter the orifices and produce jets, the outside of each jet being formed from the bottom disc in the block. Beyond a certain height above the die it has been already seen that the layers are not affected by the formation of the jets; and in the lower or active portions of the block the horizontal displacement is determined by the relative sizes of the two orifices. Thus if the layers nearest to the smaller orifice are sufficient to feed the jet from that orifice, it will be found that the upper layers on the other hand will flow exclusively towards the larger orifice. The material contained in the portion of the block intervening between the two orifices is therefore drawn by the general motion towards the larger orifice; in consequence of which the tubes in the smaller jet become thinner on the side nearest the larger jet, and their transverse sections become at first oval (Fig. 14), then pointed (Fig. 12), and ultimately (Fig. 10) do not even reach the plane that passes through the axes of the two jets. At the same time also the tubes of the larger jet, which were at first circular (Fig. 15), become gradually pointed on the side nearest the smaller jet (Fig. 13), until ultimately (Fig. 11) the material of the innermost layer penetrates completely through the outer tubes surrounding it.

Experiments have also been made with a die having a circular orifice in the centre and six smaller holes arranged round it, the diameter of the block being only 1·18 inch. In this case the tubes of the central jet, instead of being circular in transverse section, were hexagonal, the rounded angles of the hexagon corresponding with the positions of the six smaller jets. A similar alteration of form was observed in the discs composing the block, which were depressed into grooves radiating from the centre towards each of the smaller orifices, with a well-defined elevation intervening between each groove; and the same effects were produced with great regularity in a number of trials. For imitating the circumstances of a liquid flowing under a constant head, the piston was advanced only through the thickness of one disc at a time, and a fresh disc was then added on the top of the block so as to keep the height of the block practically constant. Each stroke of the piston produced a slight lengthening in the central jet and in each of the six lateral jets; and the whole of these were afterwards cut open for examining the distribution of the material in them. On separating the successive layers composing the central jet, it is seen that each disc in the original block is here represented by a sort of conical sheath, in the form of a hexagonal pyramid with its apex and angles rounded off.

Each of these layers envelops the next layer above, which is exactly similar, the contiguous faces of the two becoming separated from one another at a short distance above the bottom of each sheath. Each of the layers constituting the jet thus forms a sort of tulip flower with six petals united at the base; and this striking analogy of shape may be expressed by saying that in this way flowers have been really formed in lead, as simply the natural and mathematical result of forcing a number of layers of lead to flow through several orifices simultaneously.

Jets have also been formed with ceramic compositions, employing a die having a circular hole drilled in the centre, and three smaller holes arranged round it in the angles of a concentric equilateral triangle. The separating surfaces of the layers were rendered visible in these cases by powdering each disc with finely pulverised *fuschine* or calcined red sand, before making up the block.

In another experiment a die was tried containing ten orifices of 0·12 inch diameter, with ten discs of lead; and ten parallel jets were thus obtained, each formed as before of concentric layers. The lowest disc, which constituted the external cover of each of the jets, was drawn down into a film of extreme thinness, showing clearly to what a great extent the metal can be drawn out without tearing, when subjected to suitable treatment. It is to be remarked that the jets nearest the centre of the die are rather longer than the others, because the pressure of the piston produces a greater effect in the central portions of the block, where the movement of the particles is not retarded by the friction of the sides of the cylinder. The consideration of this difference of pressure in different parts of a solid mass evidently affords a satisfactory explanation of the displacements that are produced in the interior of the mass, since every such displacement of material from one point to another necessarily results from a difference of pressure between these two points, and the displacement occurs in the direction of the line joining the two points.

Experiments on flow through lateral orifices.—The experiments on lateral jets have been made with lead enclosed either in prisms of square section with 1·18 inch sides and variable height, or in cylinders of that diameter; and the die through which the jet issues is made in two portions, each containing half the orifice, so that the die can be separated and removed when the jet has been produced. The apparatus is shown in Figs. 2 to 4, Plate 22, and is composed of two cylinders A and B, bolted together end to end. The steel die C with a hole in the side is held tight between the two, fitting exactly at the top into the recess in the upper cylinder A, and at the bottom against the washer F which forms the base of the cylindrical space; this die is made in two halves, divided longitudinally through the centre of the side hole, as shown full size in Fig. 17, Plate 26. The lead block to be operated upon is placed on the base F, and the pressure being applied by means of the piston E, Fig. 2, a lateral jet is forced to flow through the hole in the die, as indicated by the dotted lines J.

For the first series of experiments, the cylinder was filled with superposed discs; while in the second series, which proved far more interesting in the results obtained, cylindrical blocks were used, formed each of concentric tubular layers.

In the first series, with a pile of superposed discs, the circular orifice for the jet was 0·59 inch diameter, with its centre at a height of 0·79 inch above the bottom of the cylinder; the fifteen discs to form the jet were each 0·12 inch thick, so that there were four discs below the lowest edge of the orifice, five discs in front of the orifice, and the six remaining discs above. On the pressure being applied, the edges of the discs opposite the orifice were first forced out, and these discs becoming thinner allowed the upper ones to descend to the orifice, so as in their turn to join in the general movement towards the jet. An examination of the jet produced shows at once that the different layers in the original block, which were all of equal thickness, make their appearance successively at equal distances on the upper surface of the jet. The specimens produced also show the thinning of the layers in the jet as its length increases; and certain parts of the block show that the material below the orifice also participates, though only to a slight extent, in the formation of the jet. The same facts are arrived at in the case of lateral flow through square orifices, whether the sides of the orifice be parallel and at right angles to the axis of the block, or all inclined at half a right angle to it. One of the square jets is represented full size in longitudinal section and plan in Figs. 16 and 17, Plate 26; in this case nineteen discs of lead were employed, each 0·12 inch thick, the original height of the block being indicated by the uppermost dotted line DD; and the lateral jet flowed through the square orifice shown in Fig. 18.

In the second set of experiments, the cylindrical block was in each case composed of a series of concentric tubular layers, being a portion of one of the original cylindrical jets of 1·18 inch diameter, shown in Fig. 5, Plate 23, formed from the cylinder of lead discs 3·94 inches diameter flowing through a concentric circular aperture at the bottom. Transverse sections of one of the compound lateral jets thus produced are shown double full size in Figs. 19 to 22, Plate 27. With a pressure of about 15 tons acting upon the cylindrical block of 1·18 inch diameter, the lateral jet began to issue through the circular orifice of 0·59 inch diameter; and on continuing the pressure, the jet was formed very regularly in the shape of a cylinder which became slightly curved upwards at its extremity. This jet of course ceased to be cylindrical as soon as the piston came down to a level with the top edge of the orifice C, Fig. 23. As the piston descended below the top edge of the orifice, the jet became flattened at the top, as shown in Fig. 22, to the extent that the orifice was obstructed by the piston; and along this flattened surface of the jet were shown the transformed outlines of the concentric cylinders forming the original block. On separating the successive layers of which the jet was composed, it was seen that the outside layer remained continuous throughout, having been transformed from the original vertical cylinder to a horizontal tubular jet closed at the outer end, and covering a series of similar tubes formed from each of the successive original concentric cylinders.

Transverse sections of the jet showed at the outer end only a few lines of division between the layers; but nearer to the jet orifice the number of lines was equal to the number of layers in the original block; and still nearer the jet orifice, the number of lines was further increased, showing a double curvature of the surfaces, causing them to be cut by the section in more than one place. Thus the lines of division, after being changed from circular to nearly elliptical, as shown in Fig. 19, became still further changed near the jet orifice to a figure 8, as shown in Figs. 20 and 21. A vertical section through the axis of the original block after the production of the jet shows, as in Fig. 23, that each of the ten original cylindrical rings is divided into two distinct portions, one below the jet orifice and the other above, which are separated by the material that was originally opposite to the jet orifice C; and it is seen in this case that with regard to the five innermost cylinders the separation is completely effected by the intervention of the sixth ring, while in the four exterior rings it is indicated by the inflexion of the material at that part.

On laying open the upper layers of the jet and exposing the surface into which one of the interior cylinders of the original block had been transformed, it was seen that each original vertical concentric cylinder forms individually a horizontal cylindrical jet, which joins the original vertical cylinder by curved sides in the form of a letter Y, the forking of which corresponds to the insertion of the jet into the block. Consequently the transverse section of the jet through the outer single leg of the Y shows only a single series of rings; but a transverse section passing through the two branches of the Y shows a figure 8 in the section. It has to be considered that the whole of the material in the block under pressure follows a current flowing outwards from the interior, of which the jet is the result; and the portion below the level of the bottom of the orifice is also included in this action, but forms only a weaker current, which is in fact a kind of eddy, and is found in the lower part of the jet.

The following conclusions are established by this experiment:—

First, that the pressures exerted on the surface of a solid body are transmitted throughout the whole interior of its mass, and tend to produce in it a flow which is propagated from particle to particle, and which necessarily developes itself in the direction where the resistances to the flow are the least.

Second, that the pressures thus transmitted determine in a fixed order the expulsion of the material through the orifice, and the changes of form at each point.

Third, that the transmission of pressure is unequally distributed, as the particles situated at the orifice do not participate in the flow to the same extent.

Fourth, that a loss of pressure thus takes place, which is variable; so that for solids even more than for liquids it may be said that there is loss of pressure between one point and another during the change of form. The examples of hollow jets show that there are even points where the loss of pressure is carried so far that the pressure becomes *nil*. The experiments in forging subsequently referred to have even given in certain instances a measure of this loss of pressure, and allow of pointing out precise rules corresponding to each of the changes of form that may be effected by mechanical action.

The investigation of the laws of the distribution of the pressure within the mass is of a nature to supply engineers with precise data applicable to all operations designed to change the form of a body; and with this view it is now intended to examine more particularly the influence of the losses of pressure and of the theory of the flow of solid bodies in the processes of rolling and forging iron.

In a large number of manufacturing operations the object aimed at is the conversion of a solid body into a determined form by mechanical processes more or less similar to Rolling or Forging. It is proposed to investigate the relations existing between the displacements occasioned in these two principal modes of producing change of form, and those which have already been considered in the experiments on the flow of solid bodies. It will be preferable first to consider Rolling, because the process of rolling produces invariably the same action on the work rolled, and the changes of form effected by it are therefore remarkably simple and regular, and on that account are much more easily appreciated, presenting by their continuity a real analogy to the flow of solid bodies in the previous experiments. On the other hand, in the present state of the manufacture of iron, Forging is generally applied only to work already rolled, and the changes of form produced in forging are thus added to those effected by rolling; and hence if the results of the earlier operation were not first fully investigated, it would be impossible to trace with the necessary precision any of the effects due to the subsequent process.

In the first series of experiments on the flow of solid bodies, the material preferred for operating upon was lead, the homogeneousness and ductility of which afforded in many cases valuable facilities; and the other substances that were experimented upon, both harder and softer than lead, were tried only with a view to ascertain whether the changes of form produced in them offered any analogy to those observed with lead. In the case of rolling and forging however, the important facilities in connection with iron for obtaining rolled and forged specimens of any desired form led the writer to investigate the subject more particularly in reference to this metal, reserving lead, wax, and ceramic compounds for the purposes of verification only. But as the molecular movements effected in the interior of a block of iron by rolling or forging cannot be examined afterwards by separating the several layers, as in the case of the experimental lead plates, it was necessary to trace the displacements by making numerous sections of the metal after it had been operated upon. The best manufactured iron is far from constituting a homogeneous mass; it contains a greater or less portion of the foreign substances present in the puddling furnace; and in the successive changes of form to which the bloom is subjected these foreign substances participate in the molecular movements produced in all portions of the mass. Moreover the air oxidises all parts which are momentarily exposed to its action during the successive heats, and which are then under most favourable conditions for oxidation. It is by rendering visible this want of homogeneousness in the iron that the writer has succeeded in clearly demonstrating the whole of the displacements effected. Any difference in the chemical nature of the metal in different parts allows this diversity to be rendered still more manifest by the action of chemical reagents; and among the different methods tried for this purpose the readiest was found to be the use of a very diluted solution of bichloride of mercury. Each piece of iron having been carefully planed and faced was dry-polished with the finest emery powder on the surface of the section to be prepared; in some cases it was washed with ether, to clean it from grease. It was then dipped in the solution of bichloride of mercury until the first traces of chemical action appeared, and being afterwards dipped in a bath of pure water, the surface became gradually covered with coloured and regular marks, which when the first immersion had not lasted too long showed a succession of separate and well-defined lines. Drying and varnishing completed the operation, and the marks thus preserved could then be photographed in the most characteristic cases. It was in this way that the section previously described, and shown in Fig. 30, Plate 30, was prepared and photographed. The examination of some of the specimens thus prepared shows the principal effects produced by the processes of rolling and forging.

Rolling.—In the first operation of Rolling to which iron is subjected, after puddling and a rough shaping by the hammer, the bloom is passed through one of the grooves of a pair of rolls, the pressure exerted giving friction enough on the edges of the groove to draw the iron forwards; and it is moulded by the pressure to the section of the groove in passing through the rolls, the result being a bar or jet nearly equal in section to the area of the groove. In order that the groove may be well filled by the iron, the bloom must have been previously shaped to a section differing but slightly from that of the groove; and by afterwards passing the same piece of iron through a series of grooves gradually decreasing in size, it is gradually reduced as much as necessary in section, undergoing at the same time a corresponding increase in length. The operation of rolling may thus be considered as consisting in causing a jet of metal to flow through the grooves of the rolls from a block of rather larger transverse section; but the pressure which produces the change of form, instead of being exerted on the face opposite the aperture of the grooves, is here replaced by the friction of the metal between the sides of the grooves. The rolled bar produced may be considered to be made up of a series of elementary longitudinal fibres; and during the process of rolling, each fibre becomes transformed into a similar fibre of smaller section, this diminution in section being made up by a proportionate increase in length.

The result of the writer's observations on actual rolled bars shows that on the whole the internal changes of form are very closely in accordance with this description. A bloom was rolled of rectangular section, and a specimen was cut off it at each successive passage through the rolls, in order that by making sections of these specimens and oxidising them it might be ascertained whether the figures so produced on the oxidised surfaces were in all cases similar to one another. Four of these specimens are exhibited, as well as the photographs of the oxidised sections, and it is seen at once that they are characterised by complete similarity in almost all respects; which is sufficient to show that notwithstanding all interferences resulting from the working of the iron, all parts of the mass become really drawn out according to the law of the concentric cylindrical jet obtained in the original experiments. The same experiment was made with small round bars of iron; but in this case the details of colouring can hardly be distinguished without the aid of the microscope, and could not be photographed with sufficient clearness. The parallelism with which all the threads of the molecules parallel to the axis are drawn out is more strikingly exhibited by oxidising longitudinal sections made along the axis; a succession of parallel lines are then shown after rolling, both in round and square bars, and each bar must therefore be considered as a bundle of threads, made truly parallel by rolling, and proceeding individually from each of the distinct elements that existed in the primitive mass before the operation.

It may consequently be said that rolling produces the same result on metals as combing on textile substances, and constitutes a sort of spinning without torsion; but the bundle of contiguous filaments thus obtained is bound together by their coherence, and in the majority of cases by their welding together. These elementary filaments, which are large and irregular after the first passage through the rolls, become drawn out and reduced simultaneously with the entire bar formed by their union. They are found also, under the form of extremely fine lines, in wire from the rolls or afterwards drawn cold. The finer makes of iron are not only subjected to a series of rollings, but after this first operation which brings the metal into the state of bar iron it is cut into short lengths, which are then made up into bundles, and welded and drawn out afresh by the same means as before. Now each of the bars composing these bundles being oxidised on its surface, the oxide confined between the joints forms coloured bands analogous to the preceding ones, and these bands are thinner and more numerous in proportion as the process of making up into bundles has been oftener repeated. The different specimens exhibited show this in a striking manner, so finely are they marked from end to end by lines parallel to the axis; and the straightness and regularity of these lines would lead to the idea in certain cases of their having been drawn artificially upon the surface of the section. It will be seen subsequently how these bundles of adhering threads can be twisted, spread out, and even tied into knots, according to the mechanical action to which they are afterwards subjected in the operations of forging.

The distinct manner in which the parallel drawing-out of the fibres takes place explains numerous peculiarities presented in the constitution of bar iron. Iron is said to be of fibrous quality, when the fracture shows very marked fibres, these fibres being nothing else than the filaments produced by drawing out, after separating from the neighbouring filaments with which they were less closely united. If fibrous iron is rolled in a direction at right angles to the direction of the fibres, it becomes fibrous in this new direction, because each of the elements which formed it has been drawn in the new direction as it had previously been drawn in the first. Other metals, such as copper, zinc, &c., have more or less the same quality; and workmen using them can easily distinguish in which direction they have been rolled or drawn.

The structure of iron, as composed of contiguous filaments, appears to the writer to afford an explanation of the causes of the transformation of fibrous iron into crystalline iron after long use; and he thinks that filaments of different natures may differ also in hardness, and that the facets seen in the fracture of crystalline iron are nothing but surfaces caused by friction between the particles, arising in the molecular vibrations and consequent elastic changes of form to which iron may be subjected, according to the use it is put to. These facets should never be mistaken for the grain in iron which is originally non-fibrous ; and an examination with a magnifying glass shows that there is in fact no similarity between the two states. The writer has produced numerous facets by twisting and untwisting the same specimen of granular iron a great number of times.

In certain operations of rolling, the thicknesses of the primitive layers are not all simultaneously reduced to the same extent; which is clearly seen in rolling plates, where the ultimate work produced retains distinct traces of the original superposed layers, as shown by the lined marks brought out by oxidation in sections of these plates made either in the direction of rolling or at right angles. Some iron tubes are also shown, in which it will be remarked that these lines remain all round the transverse section of the tube, and are only interrupted at the part where the edges are brought together for welding; and this interruption of the lines of oxidation affords the means of observing in many cases the mode in which the edges of the tube were prepared before welding.

An illustration of the complete generality of the principle, that all the elementary threads parallel to the axis of the primitive solid become simultaneously drawn out, is afforded by the spinning of glass, especially that of tubes used in the manufacture of Venetian glass. At the same time that the outside diameter decreases in the drawing out, the inside diameter decreases proportionately ; and this tubular structure is found even in the finest threads, which still preserve a central hole like that in the primitive tube. If either of the surfaces of the tube be serrated, the intervals between the teeth are preserved throughout all stages of the drawing, and form grooves which remain constantly similar in all parts. The regularity of these effects could only be interfered with by bringing into action distinct causes of lateral displacement, which would then act in combination with the simple process of drawing.

If the different mechanical actions brought into play in the operation of rolling be examined more closely, and the operation be conducted so as to bring to light the individual effect of each, it is found that the changes of form may not be effected under such simple conditions as those that have now been described; and the trials made by the writer for the purpose of ascertaining the influence of each action constituting the operation of rolling have led to the following results:—

First.—A single lead plate 2·36 × 1·18 inch having been divided on the surface by very fine lines into a series of equal rectangles, and then passed between rolls, it was observed that each passage through the rolls caused all the rectangles to be lengthened, but none of them were increased in width. The longitudinal drawing-out takes place therefore under the same conditions of parallelism as before, and in the lateral direction all absence of lengthening must be attributed to the friction developed along the surface of contact with each of the rolls.

Secondly.—The same experiment having been repeated with a block formed of a number of superposed plates, the rectangles at the edges alone were made slightly wider; and it could be distinctly perceived that this widening was due to the fact that the material of the intermediate layers, not being kept in by the friction, flowed out between the two upper and lower surfaces, so as to form a kind of raw edge, the greater metallic brilliancy of which during the operation showed its origin. It was only by preventing this lateral flow that thick plates could be rolled with the same regularity as thin ones; and many manufacturers have accomplished this by using a supplementary set of vertical edge rolls in combination with the main plate-rolls; and these are now employed in the rolling of armour plates.

Thirdly.—For investigating the rolling of a cylindrical bar, the writer employed a short length of one of the cylindrical jets obtained in the original experiments with lead and formed of concentric layers. It was found that the outside layers were drawn out more than the others, and that this difference of lengthening could be increased at pleasure, by reducing the amount of drawing down in each passage through the rolls, whereby the outside tube became rolled out between the grooves of the rolls and the central nucleus formed by the internal layers, which acted as a mandril. The drawing out of the material is more rapid near where the force is applied which produces the drawing out, and this action is transmitted only partially to the layers below. The same fact is still more clearly observed in the operation of forging, as noticed afterwards. A solid cast cylinder of lead experimented upon in the same way showed the retardation of the internal portion distinctly, though to a less extent; and a funnel-shaped hollow was produced at each end, showing that the lengthening had been less in the axis than at the circumference of the cylinder.

In drawing wire, analogous forms are found when a fracture takes place, showing generally that each transverse section originally a plane becomes drawn out into a conical form in the process. The drawing of tubes upon a mandril also illustrates this action, and particularly the case of manufacturing lead pipes lined with tin, where a block formed of a tin cylinder with a lead ring cast upon it is caused to flow through an annular orifice. A remarkable illustration is afforded by the manufacture of thin metallic capsules by a single blow, a disc of metal being drawn into a deep cylindrical die by a plunger of slightly smaller diameter in a screw press; and the compressed metal being only able to escape through the small annular orifice left between the plunger and the die, a regular cylindrical film is formed by the upward flow of the metal, leaving a portion of the metal at the bottom to form the closed end of the capsule. The processes of stamping in metals are also based on the same principle of action.

Forging.—In considering the internal changes of form produced in the operation of Forging, the work operated upon, whatever its form, may be considered for the present purpose as composed of a series of cylindrical elementary layers enclosing one another. When a portion of one of the former experimental jets is taken, composed of a series of concentric lead cylinders, and is subjected to a lateral hammering, each blow of the hammer produces a flattened place, which spreads the exterior layers laterally, and causes them to enlarge gradually in circumference and become loose from one another. This unsheathing of the tubes, by forging on the outside, can be made to extend to a greater or less depth according to the character of the blows; to disengage only the exterior layers, very light blows are required, in order that the disturbing force may act only upon the exterior layers to produce flow of material. Thus forging by external blows does not produce the effect of drawing the whole cylinder as a mass; and in order to obtain this result it is requisite to prevent all lateral flow of the material by some means, such as the use of dies, which may thus be considered to act as guides for forcing the material to flow longitudinally.

Another experiment was tried with a compound lead cylinder similar to the former one, placing it between two semi-cylindrical dies, so as to compel it to extend only longitudinally when hammered laterally; and it was found that, when very light blows were used, it was still the exterior layers alone that were lengthened, the central layers not being affected; but when the experiment was repeated with a heavier hammer the result was reversed, and the central layers were more drawn out than the exterior ones, this difference being due to the effects of the loss of pressure in the interior of the mass under these circumstances.

The same principle applies when the cylinder acted upon is solid, as in forging iron; and it follows that, in order to produce any given effect, the weight of the hammer and velocity of blow have to be properly adjusted, as well as the size of hammer face for spreading the blow. This has hitherto been provided for only by the skill and experience of the workman employed; but the principle of the flow of solid bodies should lead to a more satisfactory solution, from a consideration of the changes taking place in the interior of the mass.

The jumping-up of a cylinder in forging is effected by blows applied longitudinally at the end of the cylinder; and for the purpose of examining the internal changes produced in this operation, the writer first experimented upon a cylinder composed of a series of twenty lead discs, not confined in a die, each 2·36 inches diameter and 0·12 inch thick, making a total height of 2·48 inches, as shown full size by the dotted lines in Fig. 24, Plate 28. After jumping-up by hydraulic pressure, it was found that the middle plates had thinned considerably, increasing at the same time in diameter, the material having flowed outwards from the centre to the circumference; the top plate and the bottom plate had not been enlarged in diameter, but became surrounded by the outflow of the succeeding plates, the edges of which became turned upwards and downwards respectively so as to form part of the top and bottom faces of the cylindrical block. The increased diameter of the innermost plates shows that the crushing pressure penetrates to the very centre of the mass; whilst the effects of the pressure are considerably lessened in the top and bottom plates that are in contact with the surfaces by which the external forces are applied.

A similar experiment was made with a cylinder of 1·18 inch diameter and 1·97 inch height, composed of twelve vertical concentric tubes of lead, as shown full size in Fig. 25; and the result of the longitudinal compression is shown in Fig. 26, in which it is seen that the inner layers have taken a decided bulge in the middle of the height, retaining the original diameter at top and bottom; but in the external layers this bulge occupies the entire height, the extremities of these layers being rounded off into the planes of the upper and lower faces. A corresponding experiment was made with an iron cylinder upset by forging; and in the longitudinal section prepared by oxidation to show the directions of the fibres, the original parallel longitudinal fibres were found bulged out in the middle in a similar manner, though less regularly. It has to be remarked that in the jumping-up of a cylinder composed of a series of concentric cylindrical layers there is a tendency to a separation of the individual layers; and this leads to the conclusion that in the jumping-up of iron cylinders separations will be caused between the different parallel layers, which is really found to occur in practice where iron is jumped-up exactly in the direction of the fibres.

When, instead of employing a powerful pressure, light blows only were applied to the end of a lead cylinder composed of concentric layers, the extremity was found to be spread out laterally as a flange without altering the body of the cylinder; the effect of the blows only reached so short a distance in the direction of the length of the cylinder that no displacement was produced beyond that point.

For the purpose of examining practically the effects produced in different kinds of forgings as to the changes in their internal arrangement, the writer has prepared the following sections of several different descriptions of work made for this special object: the specimens themselves are also exhibited.

First.—The first specimen is an ordinary Rivet, with countersunk head forged in a die, which is shown in longitudinal section in Fig. 31, Plate 30, drawn four times full size. This section shows that on the left-hand side the original bar from which the rivet was made has been bent bodily sideways to the form of the die for the head of the rivet; while towards the right-hand side the original vertical lines in the bar become more and more doubled back upon themselves, so as to fill that side of the die also. The effect of cutting off the rivet from the rest of the bar is also clearly indicated by the curving of all the lines at the bottom extremity, in the same manner as is observed in the shearing of large plates or bars.

Second.—The second specimen is an armour-plate Bolt, forged complete in a die with the screw thread. This is represented in Fig. 32, Plate 31, and shows clearly that the longitudinal filaments of the original bar have been deflected by the forging to form each of the screw threads, the filaments nearest the surface being lengthened and bent into the die, and followed by the succeeding filaments. It may therefore be safely assumed that a screw so produced will offer greater resistance in the threads than one in which the threads have been formed by cutting away the metal between them. The vacant spaces seen at intervals show that the action of the forging has not been sufficiently powerful for causing the die to be completely filled up; and also the iron used has not been sufficiently rolled previously.

Third.—The third specimen is a Shaft forged with a series of different dimensions, being first jumped-up in the middle, and then drawn down and forged to different sections. This is represented in Fig. 33, Plate 31, and shows that the original longitudinal filaments have been displaced into regular geometrical forms, spreading out at each increase of diameter, and returning to their parallel arrangement wherever the forging becomes parallel again; and thus the material has completely followed the laws of flow.

Fourth.—The next specimen, shown in Figs. 34 and 35, Plate 32, is a small wrought-iron Wheel Nave, forged complete in dies at one operation, at the works of Messrs. Arbel, in the same manner as in making the wrought-iron naves for railway wheels; it was stamped by a steam hammer carrying the upper die, and was made out of a piece sawn off from a bar of rolled iron of common quality, the diameter of the original piece being indicated by the dotted circle in Fig. 34. The nave was then sawn in two, parallel to the face; and the surfaces of the two sections having been polished and treated as before to develop the lines of fibre, one of the sections was again cut across the diameter B C, as shown in perspective in Fig. 35, the letters A B C representing the corresponding parts in the two sections, Figs. 34 and 35. The nave is made five-sided, with five slots into which the spokes of the wheel are afterwards welded; and the original block has therefore to be reduced in height and spread out laterally into the new form. The sections show that these changes take place simultaneously and in regular order throughout the entire mass, increasing gradually in extent towards the circumference; but it is seen that the several lines of particles do not on that account become disconnected from one another at any point. This specimen shows the superiority of forging with dies, and of ensuring the pressure reaching the heart of the work; but it may be added that, practically speaking, this process of stamping can be satisfactorily carried out only upon a large scale, and that this is the source of the success attending the very ingenious method applied by Messrs. Arbel to the manufacture of railway wheels.

Fifth.—The next specimens are a pair of Medals that have been struck for the writer in copper and in tin, at the Paris Mint, by the kindness of the engraver to the mint, M. Barre; but in place of the single blank ordinarily used, a series of blanks was substituted, for the purpose of ascertaining the changes of form in the interior of the mass, corresponding to the altered surface of the metal, so as to allow of the operation being examined in detail. Coining a disc is an operation strictly analogous to forging with dies: between the time of the blank receiving the first blow and the time of the medal being finished, the metal of the blank enters successively into all the details of the engraving in the die; and it can be seen from the specimens of the series of blanks that the process closely resembles those in the former experiments on the flow of solids. The deepest hollow of the die may in fact be considered as an orifice, into which has to flow from the commencement of the operation the portion of the first disc that is immediately above it. The disc of metal being thin, there may be formed on its opposite face a cavity analogous to the cavities in the hollow jets produced under similar circumstances; and this is seen to have actually taken place in the present experiment, by observing that on a face which must have been hollow at one stage of the operation the flatness has subsequently been restored by the further blows of the coining press, causing edges of junction to appear where the doubling back of the plate took place. This would no doubt have been avoided if the final form had been attained by the use of intermediate dies gradually approaching to the finished form; and the experiment therefore most clearly illustrates that in stamping, as in rolling, it is necessary to limit the flow of the material by such an arrangement of successive moulds as will leave no danger that in the further course of the process the material will have to be displaced in a different direction to its previous displacement, so as to prevent the occurrence of any doubling back.

Punching.—For the purpose of investigating the internal changes of form produced in a mass of metal by the operation of Punching, the writer experimented upon a square block of lead 2·52 inches thick, made up of sixteen superposed plates, each 4·72 inches square and 0·16 inch thick, through the centre of which a hole was punched by hydraulic pressure with a punch 0·79 inch diameter, as shown in the vertical section, Fig. 27, Plate 29, the lead plates being tightened down by an iron cover-plate fixed by bolts, so as to prevent any vertical spreading during the punching. The most immediately obvious result of the operation was that the burr punched out was only 1·22 inch thick; instead of being the full thickness of the block, 2·52 inches; and as it was found that the metal forming the burr had not been increased in density, it was evident that a portion of the material which had occupied the space of the hole punched must have been displaced laterally, a transverse flow of the metal being thus produced at right angles to the direction of the pressure exerted by the punch. The subdivision of the block into the series of plates affords the means of tracing the nature of these lateral displacements; and the longitudinal section of the block and the burr after the operation showed the arrangement of the lines of joint to be as represented in Fig. 27. From this section it is seen that the top plate and the three bottom plates in the burr have preserved their original thickness, while the twelve intermediate plates have become very greatly reduced in thickness, more especially in the upper portion of the burr; showing that in the upper part of the block the resistance to lateral displacement must have been less than the vertical resistance of the lower plates.

It is also seen that the lines of joint in the burr are all of them concave towards the punch, each plate forming a small metallic capsule, enveloping all those above it in the burr, and itself enveloped by those below. Moreover on tracing out the course of the joint lines towards the sides of the burr by means of a magnifying glass, it is found that the sides of each capsule actually extend up to the very top edge of the burr, the metal of each plate being thus drawn down to an extreme degree of thinness, before the burr becomes separated from the block out of which it is punched. The same extent of drawing-down takes place in the plates of the block punched; and the consequence is that the interior of the hole in the block, instead of exhibiting the lines of joint of the several plates, presents a perfectly continuous surface from top to bottom, the hole being in fact lined by an extremely thin tube drawn down by the punch from the top plate of the block; and this tube is itself in the same manner surrounded outside by a series of similar tubes drawn from each of the successive plates in the block. In the passage of the punch through the block, each plate thus becomes first of all inflected in the direction of the hole, as indicated by the curvature of the lines of joint seen in the section, Fig. 27; and then drawn down into an extremely fine tube, which extends to the very bottom of the block, and is continuous with the sides of the corresponding capsule in the burr. The continuity of the metal in each plate being effectually preserved by the support received from the contiguity of the adjacent plates, the metal appears under these circumstances to possess a greater degree of ductility than is observed under ordinary methods of working.

In punching a hole of the same diameter through a solid block of lead of exactly the same dimensions, the same reduction of height was found in the burr punched out; and a similar reduction of height is also found in the ordinary burrs from wrought-iron plates punched cold. In the latter cases the vertical sections of the burrs when oxidised show a similar series of lines concave towards the punch, indicating the same lateral displacement of the metal in the operation of punching, and the same formation of capsules in the burr.

For the purpose of examining more fully the lateral displacement of the material in punching, the writer had recourse to the plan of producing an increased amount of lateral displacement, by punching a block of lead upon a solid base, without a die, as shown in Figs. 28 and 29; so as to prevent the formation of a burr, and compel the whole of the metal displaced by the punch to flow laterally. In these experiments circular blocks of lead were tried, only 2·36 inches diameter and 0·94 inch thick, composed of eight superposed discs, each 0·12 inch thick and 2·36 inches diameter. The block was tightened down by bolts with an iron cover-plate, the same as in the previous experiment, Fig. 27, and the hole was punched by hydraulic pressure with the same punch, 0·79 inch diameter. In the first experiment, Fig. 28, the hole was punched to a depth of 0·74 inch, leaving 0·20 inch thickness of metal below the punch; and the vertical section of the block shows that the walls of the tubes drawn down by the punch from the upper discs have a greater thickness of metal than in the previous experiment where the burr was punched out. The diameter of the block is also increased by the lateral displacement, the original dimension being indicated by the dotted lines A B; the spreading is greatest at the base of the block, and in the direction of the tool-marks left by the original planing of the iron base-plate supporting the block. The bottom edge of the block is found to have risen slightly all round the circumference, clear from the base-plate;

and this rising is accompanied by a corresponding thinning of the uppermost disc of lead, which is confined by the top cover-plate. The second experiment, Fig. 29, was made for the purpose of ascertaining whether, by punching the hole still deeper, the sides of the tubes would become increased in thickness towards the bottom, in consequence of the metal which in Fig. 28 remained beneath the punch being now forced out laterally. The hole was accordingly punched in Fig. 29 until only 0·04 inch thickness of metal was left below the punch; and the result is seen to be a sort of contortion in the curves at C C, near the bottom of the tubes; while at the same time the increase of diameter of the block, beyond the original dimension shown by the dotted lines A B, is very considerable at the base, especially in the direction of the tool-marks in the base-plate, in which direction the section of the block is taken. The rising of the bottom edge of the block round the circumference is also more marked in this experiment than in the first.

In many other manufacturing operations also, such as shearing and planing, numerous and manifest proofs are found of the general principle of the flow of solid bodies; and the writer has further experiments in hand upon these branches of the subject. The facts already established are however, he believes, sufficiently characteristic for deducing the following general conclusions upon the present subject:—

First.—That solid bodies can be modified in form according to fixed laws, when sufficiently powerful external forces are brought to bear upon them; and that, by employing obstacles such as dies for compelling the changes of form to take place in a fixed direction, a jet is produced which may be exactly compared to the jets occasioned by the action of gravity in liquids.

Secondly.—That the flow of liquids themselves is only a particular case of the action of the forces exerted upon them, and that consequently the conditions of the flow of solid bodies ought to lead to more exact knowledge respecting the flow of liquids; and the method of observation employed by the writer, by subdividing the original mass into a number of distinct parts, allows the movement of separate particles in the successive changes of form to be traced throughout the flow.

Thirdly.—That the variations made in the shape of the orifices have afforded the means of discovering movements of rotation round the axis of the jet when the orifice is polygonal or eccentric; and by increasing the number of orifices, the reciprocal influence of the jets upon one another can be ascertained, and the geometrical arrangements rendered manifest which result from the transmission of the pressures in the interior of the mass, and from the losses of pressure, which vary according to the direction. Also by causing the metal cylinders to flow through lateral orifices, extremely regular changes of form are obtained, bearing a certain relation to those obtained in the concentric longitudinal jets. The following law may therefore be considered of general application:—that when pressure is exerted upon the surface of any material, it is transmitted in the interior of the mass from particle to particle, and tends to produce a flow in the direction where the resistance is least.

Fourthly.—That by means of oxidising the sections of rolled and forged iron the movements of the interior particles are shown to have followed the same laws as in the previous experiments on the flow of solids; that in rolling, all the elements of the original piece are drawn out individually and in parallel lines, from the surface to the very centre of the bar, when the external force is powerful enough. The rolling of metals may therefore be compared to the operations of combing and drawing employed in spinning; and a rolled iron bar may be considered as a bundle of threads or fibres, which preserve their original individuality, and clearly constitute the fibrous property of certain qualities of iron; while iron plates are formed of a series of distinct sheets placed on the top of one another, and the more or less perfect welding of these sheets determines the quality of the plate.

Fifthly.—That the friction of the surfaces by which the pressure is applied may be made use of to reduce the change of form in particular directions; which accounts for a plate preserving the same width during its successive passages through the rolls and its consequent elongation.

Sixthly.—That the changes of form produced in forging may be considered as the results of successive flowings effected by each of the individual forces exerted upon the work forged. The weight of the hammer, the height of its fall, and the form and state of its face require therefore to be adjusted relatively to one another in the manner most favourable for producing the desired effect; the intensity of the blow determining the depth to which its effect penetrates, the form of hammer face determining the breadth of surface over which the blow is spread, and the state of its face determining the amount of friction to resist lateral spreading under the blow. Also in order to prevent other changes of form from occurring besides those intended, it is requisite to apply accessory resistances by means of dies or swages, which may be looked upon as channels left open to allow of the material flowing in the direction desired.

Finally.—That in every case these changes of form take place from particle to particle, according to a geometrical order which admits of mathematical calculation. The tendency of actual practice in manufacturing processes is to realise as far as possible the best conditions for effecting the required changes of form; and the theory of the flow of solids, by giving the means of proving the effect due to each cause, may be expected to lead to the adoption of definite rules in place of the present empirical methods. The writer hopes that his efforts in this direction may be considered as a useful step towards facilitating the improvements in metallurgical industry which are being so actively pursued both in France and England.

M. **Tresca** exhibited the series of specimens referred to in the several experiments described in the paper; and showed in action the process of producing by a hydraulic press a jet of concentric cylindrical layers from a block of lead composed of a number of superposed discs of 1·18 inch diameter and 0·12 inch thickness; these being placed in the hydraulic press, a continuous jet of many feet length and 0·22 inch diameter was caused to flow through a concentric hole in the base of the press cylinder, a succession of fresh discs being inserted under the ram of the press, so as to imitate the circumstances of the flow of a liquid under a constant head; and the sections of the jet broken off at all parts of its length showed a uniform series of cylindrical layers.

Mr. J. Ramsbottom considered the paper that had been read was a particularly interesting and instructive one, because it not only presented a series of results which were closely in accordance with those actually experienced in practice, but it also offered in explanation of those results satisfactory reasons derived from experimental investigation, tracing from the commencement to the end the action of the force brought to bear upon the material under operation. One important lesson derived from the paper confirmed the view which he had long entertained in connection with forging, namely that in ordinary practice the force employed in forging was often by no means adequate to the work to be done. In forging a cylindrical mass, the external portion of the cylinder was loosened from the internal portion, if the blows were not heavy enough to penetrate to the centre of the mass; and this was clearly illustrated by the experiment described in the paper with a cylinder composed of concentric layers of lead. In regard to stamping, the examples shown of unsound work pointed to the importance of not attempting to do too much at once, but of employing a succession of dies gradually approximating to the ultimate shape desired, as it was impossible to arrive at the end in a single step without incurring the risk of hollow and unsound work.

M. Tresca was glad to hear a confirmation derived from practical experience in forging of the importance of making the blows heavy enough to reach the interior of the work, by properly proportioning the weight and fall of the hammer to the work operated upon; the necessity for attending to this point was clearly seen from the experiments described in the paper, and he was convinced it was a matter of great practical importance.

Mr. W. Fairbairn believed the paper just read was the first definite attempt that had been made to determine the law of the movement of the particles in solid bodies; and the interesting experiments described and exhibited appeared to demonstrate satisfactorily that the law of molecular movement was the same in solids as in liquids, the flow of the particles under pressure taking place in both cases in the direction of least resistance. This conclusion would establish a new method of investigating the changes of form produced in solid bodies by external forces, and the results could not fail to be of great importance in connection with the manufacture and employment of iron in particular, and also in other mechanical operations. He hoped the investigation of the subject would be continued by M. Tresca, especially with a view to ascertaining more definitely the mutual relation of crystalline and fibrous iron, and the real manner in which the original crystalline cast iron became transformed into the fibrous state of rolled iron. His own opinion was that the fibre of wrought iron was neither more nor less than the crystals of cast iron elongated into parallel filaments by the processes of hammering and rolling, the metal having first been deprived of its carbon.

Mr. R. Mallet remarked that, although it had previously been looked upon as a probability that there was not any essential distinction between solids and liquids as regarded the mutual displacement of their particles under the action of external compression, and that the difference between them was merely in the degree of resistance opposed to that displacement, yet the researches described in the present paper were the first attempt he believed to establish the truth of this view experimentally; and the experiments which had been exhibited and described showed clearly that the flow of the particles of solids under pressure was analogous to that of liquids, differing only in degree. He concurred in anticipating that the further prosecution of M. Tresca's important investigations would throw light upon the conversion of iron and other metals from the crystalline state to the fibrous and tougher condition. Both these states he considered were in reality alike crystalline; and the change from the one to the other appeared to him to be due to the property of malleability, by which a metallic crystal was distinguished from all other crystals, and in virtue of which a metallic crystal admitted of change of form to any extent without losing its other properties as a crystal. Thus a crystal of quartz or of sulphate of copper, or a diamond, would be crushed to powder in any attempt to alter its shape by pressure; and admitted of no change of form without the destruction of its crystalline condition. But if a crystal of gold, such as the small dodecahedral crystals found in Brazil, was beaten out flat by the blow of a hammer into a thin circular spangle, it was found not to have lost its crystalline condition, as indicated by the directions of the striæ produced by acting upon the surface with acid; and on fusing the spangle and allowing it to cool gradually, the surface of the globule again assumed crystalline facets. The same occurred in different degrees with the cubical crystals of iron and those of other metals; whence it seemed not unreasonable to suppose that the crystals in the interior of a puddled ball of iron, for example, became in reality the fibres of the rolled bar, being simply elongated to a very great extent by mechanical means, while their dimensions were proportionately diminished in their two other axes. He had been informed of an instance in which something like a chemical change appeared to be produced by mechanical means: in attempting to manufacture brass boiler tubes by forcing the metal to flow out cold through a die under hydraulic pressure, in a manner similar to that shown in the experiment with lead which had just been exhibited and described in the paper, it had been found that the zinc of the brass was squeezed out through the die, while the copper was left behind. Probably a more accurate examination would have shown that the zinc squeezed out was still partly alloyed with copper, and that the copper left behind retained some zinc mixed with it, and probably the brass employed might have been a mixture of a definite alloy with an excess of zinc; but at any rate a separation to a certain extent of the two metals forming the brass was stated to have been produced by mechanical means.

Mr. J. Ramsbottom enquired whether the alloy of copper and zinc left behind by the partial separation of the zinc in the manner just described was found to be an atomic compound; or whether the metals might have been imperfectly alloyed in the original compound, so as to be in a state of mechanical mixture rather than of chemical combination.

Mr. R. **Mallet** replied that he had not got that information, and did not know whether the metal left behind in the press had been analysed; the main fact noticed had been that it was principally zinc which issued from the die, and principally copper that remained behind.

Mr. W. E. **Newton** remarked that the idea of altering the molecular character of a substance by purely mechanical agency had lately found expression in a proposal to manufacture steel upon that principle, by subjecting the wrought iron to a hammering upon an elastic anvil under a very heavy hammer of 2 to 10 tons weight, falling a short distance of $\frac{1}{2}$ inch to 3 inches with great rapidity of blows; the object being to produce a jarring or shivering action upon the metal, so as to alter the molecular arrangement of its particles.

Mr. J. **Fernie** observed that it was well known that a misapplication of heat caused wrought iron to lose its fibrous character and become crystalline; but he did not understand how such an effect could be produced by torsion alone, to which allusion had been made in the paper.

M. **Tresca** replied that such an opinion could not of course be advanced at present without great diffidence, to be confirmed or rejected according to the results of further investigation. He had been led however to adopt this view from the consideration that in the rolling down of an ordinary puddled ball no one fibre could extend the whole length of the bar produced; and therefore at the termination of any one fibre and the commencement of the succeeding fibre, the ends of the two would simply abut against each other without absolute cohesion; and hence it might be conceived that if any force were applied sufficient to make these two contiguous ends of fibres move relatively to each other, the result would be to "upset" the extremities of the fibres and flatten them into minute facets, polished by rubbing against each other repeatedly. This conjecture appeared to be confirmed by the experiment described in the paper, of twisting an iron bar backwards and forwards a great number of times; and an examination of the fracture under the microscope showed clearly the minute flat facets produced by the continued torsion, which presented a distinct appearance from the regular crystalline facets of ordinary non-fibrous iron. An additional confirmation of this view was also derived from the consideration that the most prominent illustration of the supposed conversion of fibrous into crystalline iron was the case of railway axles, where the strain which produced the change and deterioration of the metal was almost exclusively one of torsion; and in this case he believed it would be found on further investigation that no real crystallisation took place of the wrought iron, but only the transformation of the ends of contiguous fibres into the flat facets previously described.

Mr. W. CLAY remarked that, in reference to the opinion which had been expressed that the fibrous quality of iron was not its original and natural state, this view was confirmed by an experiment which he had recently made with Bessemer steel, for the purpose of obtaining greater toughness and ductility in the manufacture of armour-plates of that metal, so as to give them greater strength and greater resistance to the penetration of shot. With this object the steel was rolled down into narrow bands as thin as ordinary hoop-iron, and in that state it could be bent backwards and forwards and twisted in any manner without the slightest signs of cracking, showing how completely the fibrous character had been developed by the rolling. These thin strips were then made up into a pile, crossing their direction in each layer; but after reheating the pile, it was found that in rolling it down into a bar of 3 × $\frac{3}{4}$ inch the bar broke off short, and the fracture showed that the metal had returned to its original crystalline state like ordinary steel, having lost the fibrous quality.

Mr. C. COCHRANE observed that, in attempting to explain the cause of the crystalline appearance presented by fibrous iron which had been subjected to repeated strains of torsion, it must be borne in mind that the elementary fibres were not all of the same length, and also that they overlapped one another indiscriminately; and consequently, although some of the facets observed in the fracture might perhaps be accounted for in the manner that had been suggested, by the "upsetting" of the ends of the fibres, some further explanation was still required of the crystalline appearance presented by the fibres themselves that were broken through in the middle of their length; and it remained to be shown how the individual fibres were themselves rendered crystalline throughout their whole length by the continuance of a torsional strain or vibratory action, in consequence of which each fibre appeared liable to break through at any part of its length.

Mr. J. FERNIE enquired whether any experiments had been tried with steel, similar to those made with iron as described in the paper, for tracing the changes of form produced in various processes of manufacture.

M. TRESCA replied that he had not yet made many experiments with steel, on account of the difficulty of getting any material hard enough for the dies through which the metal had to be made to flow by pressure; but he intended to prosecute the investigation further in respect to steel, as far as could be managed satisfactorily with the present means. He feared however that there was some difficulty in tracing the changes of form by the same method that he had employed for iron, because the surface of the steel was so much more difficult to oxidise, for examining the results of forging and shaping &c.; and moreover the lines which were seen in the specimens exhibited of iron, in consequence of its laminated structure, were not met with in steel, where the only corresponding indications were the series of minute dots or "eyes," resulting from globules of air imprisoned in the steel and oxidising the surfaces of the minute chambers containing them. These air holes were more particularly apparent in Bessemer steel, owing to the mode of its manufacture; and he had even met with some specimens which could hardly be said to have any real solidity, on account of the continuity of the metal being so greatly interrupted by the large proportion of air holes which they contained. In the subsequent rolling or hammering of the metal, these holes became elongated, and produced a striated appearance upon the prepared surface, similar to the lines observed in the specimens of iron exhibited; and in such a case the changes of form could of course be traced in the same manner as in iron. The most remarkable instance that he had met with of freedom from these air bubbles was in the case of a Bessemer rail manufactured at the Imphy Iron Works, near Nevers in the department of Nièvre; and he had ascertained that the method adopted at those works was to pour the melted metal into a revolving vessel driven at a considerable speed, so as to clear the steel of air by rapid rotation, the metal being thrown against the sides of the vessel by the centrifugal force, while the particles of air from their greater specific lightness were displaced and expelled at the centre. This method appeared very effective in practice, in freeing the steel from the minute air bubbles which it contained on leaving the converting vessel or the melting pot.

The President considered the investigations described in the paper were such as would lead to most important practical results in dealing with iron and steel and other metals; the subject was evidently one which would amply repay careful study; and they were greatly indebted to M. Tresca for his extensive and carefully conducted experiments.

He moved a vote of thanks to M. Tresca, which was passed, for his paper and for the valuable and interesting set of specimens which were exhibited, showing the practical application of the paper to the processes of ordinary work.

The following paper was then read:—

ON MECHANICAL PUDDLING.

By Mr. WILLIAM MENELAUS, of Dowlais Iron Works, Merthyr Tydvil.

During the last few years various attempts have been made to apply machinery to the purpose of Puddling Iron, by adapting it to the ordinary puddling furnaces, where it is made to do the heaviest portion of the work, but leaving the workman to exercise his skill in guiding the tools, and in working and finishing the heat much as in the old way. Special machinery for this purpose was invented and first used, the writer believes, in France; and a great deal of ingenuity has been expended upon the subject, both in France and England. In England, although the machines were somewhat simplified, and rendered as perfect as machinery of the kind can well be made, they have not met with much favour, and very few are now at work; but these machines have not received the attention and encouragement which in the writer's opinion they deserve.

Other attempts have been made to dispense with manual labour altogether in puddling, by giving motion to the furnace itself, in order to produce the necessary agitation in the metal, and so render the use of tools nearly or altogether unnecessary. One plan is to impart a rocking motion to the furnace; and in another the bed of the furnace is made to revolve on a vertical axis, or an axis slightly inclined from the vertical. Another plan was that of Messrs. Walker and Warren, for making the furnace in the form of a cylinder, which was to be lined to the proper shape, and made to revolve on friction wheels with the axis horizontal or nearly so. No experiments on a practical scale however were made in connection with the origination of this idea, as far as the writer is aware; but it was subsequently taken up by Mr. Tooth, who made a long series of experiments on puddling in cylindrical vessels, and appears to have been the first to succeed in producing puddled balls without the intervention of manual labour. For more than twenty years the writer's attention has been directed to the question of mechanical puddling; and he has watched carefully every attempt which has been made to improve the system of puddling, either by lessening the labour of the workman or by endeavouring to dispense with manual labour altogether.

Some years since the writer commenced a series of experiments on mechanical puddling, taking the above idea of the horizontal cylindrical vessel as the one most likely to fulfil all the conditions which he held to be essential; and the purpose of the present paper is to detail the amount of success achieved, and more particularly the many grave difficulties that have been met with, some of which have not yet been overcome.

Having arrived at the conclusion that the horizontal vessel was the best, the next step was to ascertain the best form. In designing the experimental vessel, the writer took as a guide the internal area of a common puddling furnace at the bridge and flue; and made a vessel which when lined should have openings at the ends about equal in area to those of the common puddling furnaces. The middle diameter and length of the vessel were such that a heat of 5 or 6 cwts. could be worked without boiling over. The form of vessel was thus arrived at that is shown in Fig. 6, Plate 35, where the shape of the experimental vessel is indicated by the dotted lines.

The notion of bringing out the heat in several balls was discarded, because with the form of vessel adopted it would have been next to impossible to do this; and for rail-making, which is the principal trade at Dowlais, a large ball, say of 6 cwts., is a positive advantage. The size of the bridge end of the vessel is just sufficient to allow a ball of 6 cwts. to pass through, and the vessel is adapted to work a sufficient quantity of iron for producing a ball of about this weight, as shown dotted at A in Fig. 6; a specimen of the ball is exhibited to the meeting. Each end of the experimental vessel was made symmetrical in shape, as shown by the dotted lines.

The vessel is made of 3-8ths inch boiler plates, with covering strips over the joints, as shown in Figs. 6 and 7, Plates 35 and 36. Its entire length is 8 ft. 2 ins., and the greatest diameter is 5 ft. 9 ins.; the diameter of the shell at the flue end is 2 ft. 4 ins., and at the bridge end 2 ft. 10 ins. The vessel is divided vertically into two halves, which are joined by strong angle-irons. On the bridge end of the vessel is shrunk a strong wrought-iron hoop B, 6 ins. wide by 2 ins. thick; and upon the flue end another wrought-iron hoop C is fixed, of the section shown in Fig. 6; to this hoop is bolted the spur wheel D whereby the vessel is driven, which is put on in two pieces and fastened by bolts, as shown in the drawing. The hoops B and C at the ends, and the edges of the middle angle-irons, are turned up true in the lathe. The vessels are all made to a gauge, so that any vessel will work in any set of bearings. Two trunnions EE are fixed to each vessel for the purpose of lifting it out of its bearings, and also for tipping it; these trunnions are firmly bolted to the middle angle-irons, and are fixed as nearly as possible in the centre of gravity of the vessel when lined.

After completing a series of experiments with a single vessel, a Forge for containing eight working vessels of slightly modified form was designed, as shown in Figs. 1, 2, and 3, Plate 33, one half of which was erected, with the charging and tipping arrangements, a steam hammer for working the balls, and a steam crane for lifting the vessels. With these four vessels a large quantity of iron has been made and a great number of experiments tried.

Figs. 9 and 10, Plate 37, show a side and end view of the vessel in position for receiving its charge. Although cold iron may be charged into the vessel and melted in it in the ordinary way, arrangements were made for running it in hot from a blast furnace, to save time in melting. A strong wrought-iron loop F suspended from the steam crane is hitched to the trunnions E of the vessel; the ends of this loop drop into sockets in the strong cast-iron frame G which supports the vessel while it is being charged. After the charge is run in by the spout at H, the vessel is lifted by the crane and placed in its proper bearings, where it is immediately thrown into gear, and the operation of puddling commences.

Figs. 11 and 12, Plate 38, show the vessel in the position for tipping. When the heat is finished the vessel is lifted by the crane from its bearings, and placed in a cast-iron frame, the ends of the loop F passing through holes in the side brackets JJ to keep the vessel in position. A clutch I is then thrown into gear with the trunnion E by the lever K, and by turning the spindle L with a common winch handle, the vessel may be tipped with ease in either direction. The cinder is first discharged from the small end; and then for discharging the ball, the bridge end of the vessel is turned down, as shown by the dotted lines in Fig. 11; and the ball drops out upon a carriage, ready to be taken to the hammer. The vessel is then brought back to a horizontal position and lifted by the crane into the charging frame previously described, whence it is again taken when filled to the driving gear for puddling.

Figs. 4 and 5, Plate 34, show an end elevation and plan of the driving machinery, and the position of the vessels when at work. The vessels are arranged in pairs, each pair being worked by a small 8-inch cylinder engine M. The vessel A is shown on its bearings, while its fellow is removed so as to show more clearly the framework and the friction wheels NN upon which it rests when at work. The firegrate P, Figs. 5 and 6, is of the same dimensions as the grate of an ordinary puddling furnace; and the flue Q communicates by an underground culvert with a chimney common to four puddling vessels, as shown in Figs. 1 and 2. The fluebox is fitted with a door R, like a common puddling furnace door, and a damper S, as shown in Fig. 6. Rings of angle-iron are bolted to the throats of the firebox and fluebox, as shown in Fig. 6; these rings are concentric with the hoops B and C on the ends of the vessel, and a space of 2 or 3 inches is left at each end between the hoops and the angle-iron rings. These spaces are closed by a telescope joint by means of thin bands TT sliding upon the angle-iron rings; and these bands may either be made to close the joints entirely, or may be left partially open for the admission of air at the firebox end, as much as the workman considers necessary during the process of puddling. When the vessel is being lifted out of its bearings these bands are slid back, so as to allow a few inches of clearance between the vessel and the fixed firebox and fluebox.

The vessels are driven by spur gearing, as indicated in Fig. 4; and either vessel of the pair may be disengaged independently of the other, by sliding its driving pinion out of gear. When at work each vessel rests upon the friction wheels NN of large diameter, as shown in Figs. 6 and 7. At the flue end these wheels fit into a groove in the end bearing C of the vessel, Fig. 6, so as to prevent end motion.

Figs. 1, 2, and 3 show the general arrangement of the forge as designed, one half of which was erected at the Dowlais Works. The puddling vessels A A are arranged in pairs round the steam crane U, Fig. 2; V is the position of the vessels when being filled with their charge from the blast furnace W, and X is the position when they are being emptied. The steam hammer for reducing the balls to square blooms is situated at Y; and Z Z are small cranes for lifting the vessels when they are being lined. The circular arrangement of the puddling vessels round a central crane has been chosen by the writer as the one best suited to the situation; but they may be arranged in lines, or in any other manner which may be deemed most convenient for working and handling them.

The chief difficulty in puddling in revolving vessels is to get a lining which will withstand the chemical action of the melted metal and cinder, and the mechanical action of the iron from the time it comes to nature until it is balled up. The successful use of "ganister" for lining the Bessemer converting vessels led the writer to try this substance, and the vessels were in the first place lined with ganister rammed in in the same way as in the Bessemer converters. The linings of ganister stood on the whole very fairly, but the iron produced was cold-short; and although various devices were used to get over this grave defect, they have not been entirely successful. Various linings have been tried, indeed almost every likely substance, and some of them in various forms. One of the most successful was what is known as "titanic ore" from Egersund in Norway, introduced to the writer's notice by Mr. Riley. This substance was used in solid blocks in its natural condition, and also finely ground, tempered, and rammed in the same way as the ganister linings; it stood very fairly, particularly in solid blocks, and the iron produced was of a better quality than with the ganister lining, being less cold-short, and also free from red-shortness when properly treated in the furnaces. The titanic ore and the ganister were found on the whole the best of the materials used for lining the puddling vessels, and they may be taken as types of the various substances tried.

The linings were put in in various ways. Sometimes the material was used in its natural condition, as in the case of the titanic ore; and sometimes it was reduced to powder, tempered, and rammed round a core, and then carefully dried *in situ*. In other cases the ground material was made into bricks of the proper size and form to fit the vessels, and these were burnt in the usual way, and set carefully in the vessel with cement, generally of the same material.

Some of the substances tried for lining, from which better results might have been expected, failed signally: in this class were "bulldog" and "puddling ore." As soon as it was known that experiments were being made at Dowlais on a large scale, suggestions were sent to the writer from all quarters, mostly from England, but many from the continent of Europe, and some even from America. The writer may fairly say that he gave every feasible suggestion a fair trial, when it was practicable to do so. A lining of iron in imitation of the common puddling furnace was a favourite plan with many, and to test it the writer had a vessel lined with iron bars, placed on edge in the longitudinal direction and firmly secured to the vessel; the spaces between the bars were filled and rammed hard with one of the best lining materials. The bars were for the purpose of preventing the lining from being abraded by the action of the granular iron in the course of puddling; and it was hoped that the lining in its turn might prevent the iron from adhering to the edges of the bars. As was feared however, the iron stuck fast to the bars wherever their edges were exposed, to such an extent that in one instance the whole heat adhered to the sides of the vessel. As far as the writer's experience goes, it is next to impossible to prevent the puddled iron from adhering to the *clean* surface of an iron lining, heated to the temperature necessary for puddling.

It was observed that with the natural draught through the vessels the action produced on the charge by the oxygen of the air was not so marked and effective as in ordinary puddling furnaces; which was easily accounted for by the form of the vessels, the iron not being so directly exposed to the action of the air passing through the furnaces. To remedy this defect, blast was introduced at the firebox end, and made to impinge upon the surface of the charge. This had a marked effect in improving the quality of the iron; it removed a great portion of the impurities, and as a consequence produced a cinder richer in iron and more closely approximating to that of the ordinary puddling furnaces.

Although the quality of iron produced was not altogether satisfactory—and this is the great difficulty still to be solved—the quality was wonderfully uniform: there was no bad puddling in the ordinary sense, the iron being all perfectly and uniformly worked.

The results here briefly stated were arrived at by a long series of experiments on mechanical puddling, made with great care, and on a scale sufficiently large and practical to render them thoroughly reliable; and the writer's aim in the present paper has been to give a complete account of all that has been done at Dowlais in trying to cheapen and improve what is perhaps the most important process in the iron manufacture—a process that appears likely to hold its ground in some form or other for very many years, inasmuch as it is the only method at present known by which on a large scale the great bulk of the pig iron made can be converted into malleable iron or steel. Although by the Bessemer process certain qualities of pig iron can be converted into a material which for nearly every purpose is greatly superior to the malleable iron produced by puddling, this method unfortunately admits only of dealing with iron practically free from certain impurities that are common to the great bulk of the pig iron produced in almost every country; and thus the application of this highly ingenious and beautiful process is limited. It seems not improbable indeed that the Bessemer process, even yet in its infancy, may owe its full development to puddling; for it has already been practically demonstrated that steel of excellent quality can be made from common pig iron purified by the puddling process, and therefore the expense of puddling seems to be the only obstacle in the way of its application for preparing common pig iron for the Bessemer converters.

Looking at the subject of iron manufacture as a whole, there appears to be no commercial question at the present time of so much importance to the world at large as that of cheapening the mode of purifying crude iron. At present this is effected by such a combination of high skill and severe manual labour as can only be purchased at great cost; and this cost will doubtless go on increasing, unless something is done to lighten materially the labour of the puddler and so render his occupation more endurable. In England it may be said that the extension of the iron manufacture is limited by the supply of labour in this particular branch; and there are serious doubts whether under any circumstances the supply will keep pace with the demand.

Mr. **Menelaus** showed one of the puddled balls that had been produced in one of the puddling vessels at Dowlais, the weight of the ball being about 6 cwts.

The **President** enquired whether there was a greater liability of the cinder becoming wrapped up in the ball in that mode of puddling, on account of the ball being formed by rolling over and over in the revolving puddling vessel.

Mr. **Menelaus** replied that the risk of wrapping up cinder in the ball was not found to be greater than in ordinary puddling; and although the actual quantity of cinder contained in the ball was greater, that was only in proportion to the increased size of the ball itself produced from the puddling vessel.

Mr. C. W. **Siemens** remarked that the subject of puddling iron was one that he had been engaged upon for some years, with the object of improving and economising the process, and he was satisfied that any improvement such as the one now described, which could dispense with the toilsome manual operation at present prevailing, would be of very great value. In reference to the plan tried at Dowlais, the one difficulty which had principally struck him was, how to make a lining for the puddling vessel which should stand for a sufficient length of time to be practically successful; and it appeared from the paper just read that this had been found the chief practical difficulty in the experiments, and that it had not yet been successfully overcome. In his own trials of puddling furnaces he had found that the particular part where the lining failed was all along the line of the surface of the melted iron, and in the revolving puddling vessel now described that line was continually changing.

In the new mode of puddling now described, one point upon which he would be glad of further information was, whether there was sufficient means of watching the operation during its successive stages, so as to regulate the nature of the heat given. In the ordinary puddling furnaces a melting heat was first required, for reducing the metal to a fluid state as rapidly as possible; but in the present instance the melting was not done in the puddling vessel, the melted iron being run in direct from the cupola or blast furnace. Then came the period of stirring, an operation which required great attention, because if the iron was deprived of its carbon or "came to nature" too soon, it would not mix properly with the cinder, and therefore a great deal of the foreign matter originally contained in the iron would remain in it, instead of being removed by the cinder. During this operation the condition of the metal could be completely watched in the ordinary puddling furnaces, through the door at which the puddler's tool or "rabble" was inserted. A smoky or reducing flame was necessary until the metal had become sufficiently freed from impurities; after which a keen oxidising flame was employed, to cause the crystals of iron to be formed, and finally prepare the metal for balling up. In the revolving puddling vessel described in the paper he did not see that there could be the same means of watching the progress of the process.

In regard to the mode of introducing the flame from the firebox into the revolving puddling vessel, it struck him as objectionable that the axis of the flame coincided so nearly with the axis of the vessel; and it appeared to him that what was wanted was to get the direction of the flame more inclined to the axis of the vessel, as the flame was required to strike downwards upon the metal, instead of simply passing over it parallel to its surface. This was not so easy to manage with the revolving vessel as in an ordinary puddling furnace, unless it were done by the aid of a blast applied in an inclined direction; but then the employment of blast would be attended with an extra loss of the metal itself by oxidation. He thought however that a regenerative gas furnace would remove this difficulty, by allowing of the flame being introduced in an inclined direction without requiring the use of blast.

He enquired also whether the actual loss of metal in puddling by the revolving vessel was found to be greater than in the ordinary puddling furnace. The question of commercial economy was perhaps of secondary importance, in comparison with the primary consideration of the practical success of the process for the manufacture of iron; and the mechanical arrangements for performing the operation of puddling appeared certainly to be well carried out.

Mr. F. J. **Bramwell** enquired what was the rate of revolution of the puddling vessel, and whether it was uniform during the whole time of the operation; and also what was the length of time ordinarily occupied, from the time of running the melted iron into the puddling vessel until the finished ball was ready for turning out. He asked also whether any red ore or other material containing iron was employed for lining the puddling vessel, as was done sometimes in ordinary puddling furnaces, and if so in what quantity it was used and how it was applied; because in some instances of an apparently high yield obtained from puddling furnaces in which a large proportion of red ore was used for the lining, he believed that part of the yield was really due to the reduction of the lining itself during the process of puddling.

Mr. **Menelaus** said that the first object which he had aimed at in the endeavour to accomplish mechanical puddling had been to obtain a good result in regard to the quality of material produced, before attending to the question of commercial economy; but he must frankly admit that all the attempts which had been made at the Dowlais Iron Works during several years past had not yet resulted in success; and so far indeed was the process described in the paper from proving yet a practical success, that at the present time the puddling machines were all standing idle. The importance of lightening the puddler's labour was very seriously felt at Dowlais, where there were as many as 150 puddling furnaces to be kept constantly at work; and great difficulty had been experienced in finding regularly a sufficient number of men to work so large a number of furnaces. If the laborious part of the process could be lightened, men could more easily be got to perform the rest of the work; but there were so many conditions essential to successful puddling, that it was extremely difficult to substitute mechanical agency for the present manual labour.

The means of watching the process of puddling in the revolving vessel was through the end door (R, Fig. 6) in the fluebox, and the damper in the fluebox allowed of regulating the heat in the vessel; and in both these respects the facilities afforded in the new plan were as great as in the ordinary puddling furnaces. The direction of the flame entering the puddling vessel from the firebox was originally parallel to the axis of the vessel, the mouth of the firebox having been built cylindrical in the first instance, the same as the mouth of the fluebox at the opposite end of the puddling vessel; but afterwards the brickwork was altered, by making the top of the firebox mouth to slope downwards (as shown at M, Figs. 6 and 8), so as to deflect the flame down upon the metal in the puddling vessel as much as possible. It was not easy however, on account of the shape of the puddling vessel, to deflect the flame to the full extent that was desirable, though this was readily managed in the ordinary puddling furnaces.

The rate of revolution of the puddling vessels in working was about six revolutions per minute during the time that the iron remained liquid; but the speed could be varied at will, and during the balling up it was reduced to two or three revolutions per minute. One man attended to a pair of vessels, and each vessel turned out six heats per day. Although the melted metal was run direct into the puddling vessel, to save the time and expense of melting it down in the vessel, the slight saving of time thus effected was not sufficient to admit of increasing the number of heats worked in the day, because by far the greatest portion of the time was occupied in the operation of puddling. In regard to the use of red ore in the puddling vessel, it was necessary in all puddling furnaces to introduce oxide of iron in some form; this was used in the revolving vessels in the same way as in ordinary puddling furnaces, and among other substances he had used the red ore for the purpose. The loss of iron in puddling was very nearly the same as in the ordinary furnaces, being about 2 or 3 cwts. per ton of pig metal charged into the furnace.

The PRESIDENT enquired about the durability of the lining of the puddling vessel, what had been the greatest number of heats that had been worked in one vessel before it required to be relined; he supposed it was the question of lining which would principally determine the ultimate success or failure of the plan of mechanical puddling now described.

Mr. MENELAUS replied that he attributed the present failure of the attempt solely to the failure of the lining in the puddling vessel; the chemical action of the melted metal and cinder, together with the mechanical action of the iron in its granular state, soon wore the lining away, and it got mixed with the iron, which was consequently rendered inferior in quality; little or no injury was done to the lining by the rolling of the iron when balled up. One of the best lining materials was ganister, which had been found to stand about one hundred heats. Another lining had been made of hard cinder and red ore, liquefied in the vessel, and allowed to cool gradually while the vessel slowly revolved, so as to line the interior with a uniform coating; but this lining, like the others, had failed.

Mr. E. WILLIAMS said he had seen the puddling machines at work at Dowlais, and he was at a loss to understand why there should be any more difficulty in watching the process and regulating the heat during the whole of the operation than there was in the ordinary puddling furnaces. There appeared to him to be quite sufficient facility for seeing the metal through the door in the fluebox;

and for regulating the heat the puddler could have recourse either to the damper or to the fire itself. While witnessing the experiments at Dowlais he had been much struck by the very efficient stirring produced by the revolving puddling vessel, which was better than any stirring by the ordinary mode with a rabble. As the iron began to come to nature it adhered to the side of the revolving vessel, and was carried up until it fell over again to the bottom in a sort of spray; and in this way it was exposed most completely to the action of the flame.

With regard to the sand lining of the revolving puddling vessel, it produced exactly the same evil that existed during the earliest years of puddling, when the furnace bottom was sand, and the quality of the iron worked in the furnace was thereby greatly injured. Some thirty years ago the cast-iron furnace-bottom was introduced, from which the greatest advantage resulted; in fact this was the chief improvement that had been made since the original invention of puddling. In the revolving puddling vessel the essential difference from an ordinary puddling furnace was that the part which was at one moment the bottom of the furnace formed at the next moment the roof; and the lining would not stand the heat. He thought however that a wrought-iron vessel might be lined with strong cinder, and suggested that a plentiful stream of cold water should be applied outside in order to set the lining. There would probably be some need of experiment to determine the thickness at which this lining would stand; but he felt sure such a lining could be made to stand, and if so it would be better than any other. He did not think that any one who had seen what had been done at Dowlais would regard the attempt as having failed; the lining of the puddling vessel was at present the only failure; and all the mechanical arrangements appeared very good.

Mr. E. W. RICHARDS said that he had also seen the experiments on mechanical puddling while in progress at Dowlais, and thought the process was remarkably simple as there carried out; and he fully concurred in considering the results thus far arrived at as most satisfactory, the only serious difficulty that yet remained being the lining of the puddling vessel.

Mr. E. Riley said he had seen the puddling vessel at work at Dowlais, and had witnessed many of the experiments with different sorts of lining; and he thought the best course to pursue would be to endeavour to apply the same material that was found to stand best as the lining of ordinary puddling furnaces. The material found most durable for this purpose he believed was what was known as "best tap cinder" from the balling or reheating furnaces with cast-iron bottoms, which was delivered to the puddlers for fettling their furnaces; it was found so satisfactory that it would no doubt be used more extensively if it could be obtained in sufficient quantity. The best chance of success he thought, in lining the revolving puddling vessel, would be to run this material into moulds like bricks, of suitable shape to fit the vessel, and then thoroughly anneal it by cooling it very slowly. The casting of the material in moulds could be very readily done, and although the lining would no doubt wear away very rapidly at first, he concurred in thinking that the wear would only continue to a certain extent, and that the thickness of the lining would thus regulate itself. He had little doubt that the titanic ore, referred to in the paper, if it could have been cast into bricks in the same way, would have answered for the lining of the puddling vessel; but the only experiments tried with it were made by grinding it up and pressing it into moulds by hydraulic pressure, and when used in this way it did not answer. He suggested also that a trial might advantageously be made with the "best tap cinder" mixed with some of the titanic ore, or with hæmatite or magnetic oxide of iron now obtained from Sweden; for having had some experience in the use of a material of that composition for fettling, he had found its property of resisting fire to be very great.

With regard to regulating the heat and watching the process of puddling, he thought these points were as successfully attained in the revolving puddling vessel as in an ordinary furnace. The real difficulty at present was the lining; and when that had been successfully overcome, any further points could then be considered that might require attention.

Mr. E. **Williams** observed, with regard to the cinder fettling which had been referred to, that he used a large quantity of that material for the puddling furnaces at Middlesbrough; and one of the best ways of making it was found to be by mixing with the cinder a quantity of the scale from the shingling hammers and roughing-down rolls, and even a few scraps of bar iron. The whole was then melted down in a very hot furnace, and run into blocks, which were built against the sides of the puddling furnaces as needed. He had also himself constructed an experimental puddling vessel similar to those at Dowlais, but of smaller size, 6 feet long and 3 feet diameter, which he had succeeded in lining with this "iron fettling" by letting the material run in very slowly, keeping the vessel revolving gently. By this means he had succeeded in getting a lining 2 inches thick all over the inside of the vessel, the outside being kept as cold as possible during the time by a stream of cold water; and he hoped to continue the experiments with this lining. One point of importance he considered was that the vessel should only puddle a single heat, and should then be allowed to cool down while the next heat was worked in another vessel; and he thought this mode of working would materially increase the durability of the lining. It was decidedly preferable he believed to run the melted iron into the puddling vessel, as had been done at Dowlais, instead of melting down the charge in the vessel; the cost of melting the iron in a separate furnace was less than in the puddling vessel.

The **President** enquired how far the destruction of the lining had been found practically to affect the quality of the iron produced from the revolving puddling vessel, as compared with that worked in ordinary puddling furnaces.

Mr. **Menelaus** replied that the iron was so much impaired in quality as to be not marketable, when this destruction of the lining took place to the greatest extent.

Mr. I. L. **Bell** remarked that the very candid admission respecting the quality of the iron produced by the mechanical puddling led him to infer that there were other conditions to be considered, besides those of a mechanical nature; and the character of those other conditions might be illustrated by a reference to another manufacturing process.

In the manufacture of soda, where the object was by application of heat to convert the sulphate of soda into carbonate of soda, the main difficulty was to ensure the perfect decomposition of all the material; but if this were not completely effected, the result was only a loss to the manufacturer, by interfering with the available produce of soda, whilst the quality of the soda actually produced was not deteriorated by the presence of small quantities of the original raw material remaining undecomposed. In the manufacture of iron, on the other hand, a different class of difficulties had to be encountered, because the presence of even a small proportion of sulphur or phosphorus was a contamination fatal to the quality of the metal, and the greatest amount of skill was required to get rid of these ingredients. The puddler judged from the appearance of the metal in the furnace what variations were required to be made in the flame by regulating the supply of air; but so much was this still a mere matter of guesswork, that even in working the same materials nothing was more difficult than to secure the same uniform quality of iron throughout; and he had found that on no two days was the quality precisely the same, notwithstanding the greatest care to ensure uniformity in the materials. One very encouraging feature therefore of the trials at Dowlais was the remarkable uniformity which was stated to have been experienced in the quality of the iron produced; and although the iron produced was not satisfactory at present, yet the uniformity in the quality must be looked upon as a point of much importance, because it might fairly be expected that, when the difficulties which now beset the process were ultimately overcome, means would thereby be arrived at of producing a good quality of iron with more complete uniformity than was possible in the present condition of the iron manufacture. Hitherto attention had necessarily been directed mainly to difficulties of a purely mechanical nature; but he thought the investigation of the chemical conditions attending the process might with advantage be considered simultaneously. With regard to the construction and working of the revolving puddling vessel, he did not see any reason why the control of the operation should not be quite as easy in this case as in an ordinary puddling furnace, as soon as means were devised of maintaining the vessel in working order.

Mr. W. E. **Newton** remarked that, although the history of invention was for the most part a history of failures, it was by no means the case that the failures were so generally recorded as was desirable; and therefore they were the more indebted for the complete account now given of an attempt which had not yet issued in complete success; and if other efforts which had not at present proved successful were recorded in an equally candid spirit, with the particulars of the difficulties that had been encountered, less time would be lost in blundering a second time over ground previously tried. He agreed with the remarks which had been made as to the importance of not losing sight of the chemical questions affecting the process of puddling, and thought it would be a mistake to attend exclusively to the mechanical features of the subject, and to endeavour to perform the whole process by mechanical means alone; and he mentioned that an attempt to supersede the present manual operation of puddling was now being made at Stalybridge, by means of both chemical and mechanical agencies in combination, and the experiments had been attended with partial though not complete success. As the object of the puddler's labour in stirring the metal in the furnace was to expose all portions of it to the action of the air, in order to effect the oxidation or decarbonisation of the original pig metal for converting it into wrought iron, there seemed no reason why this might not be accomplished by adopting Mr. Bessemer's system of forcing air from below through a mass of melted metal; and Mr. Siemens having devised the means of generating a supply of gas to be used in place of raw fuel, he suggested that a reducing gas might be introduced below the surface of the melted iron, while an oxidising flame was made to play upon the surface. By this means the process would be brought under complete control, and the puddler's labour would be greatly abridged.

Mr. **Menelaus** observed that, although mechanical puddling was the subject of the paper, and the mechanical part of the question had alone been dwelt upon, the chemistry of the subject had not been neglected, and this had been under the able supervision of Mr. Child, the chemist of the Dowlais Iron Works. The practical difficulty however which at present interfered with the success of the experiments was in his opinion almost entirely of a mechanical nature, namely the lining of the puddling vessel; and it was this point which had specially occupied his own attention. It was right to state that he had had the valuable aid for a time of Mr. E. Williams, and also the help of the best practical puddlers at the Dowlais Works during the experiments. The remarkable uniformity obtained in the quality of the iron puddled in the revolving vessel he considered was to be attributed to the fact that a machine was neither lazy nor dishonest; and therefore the same amount of work was always put into the metal, and the result was perfectly uniform. In hand puddling on the contrary it was often found that portions of badly puddled iron had been wrapped up in the ball by the puddler; and there were great variations in the quality of the iron produced.

Mr. W. **Clay** mentioned that graphite, which was nearly pure carbon, would stand a remarkable degree of heat and resist a great amount of wear and tear, and he had found it last for the sides of puddling furnaces much longer than either red ore or the best tap cinder. Another material that he had used with success, which had not the objection of re-dosing the iron with carbon, was a mixture of the graphite with iron ore. In France he believed a mixture of ground coke and tar was sometimes used for making the bottoms of puddling furnaces; he had himself tried it in one of Mr. Siemens' regenerative puddling furnaces working spiegel-eisen, and the furnace was worked continuously for nearly a month under a great heat, without the bottom requiring renewal. He enquired whether any of these materials had been tried for lining the puddling vessel in the experiments at Dowlais.

Mr. **Menelaus** replied that he had not tried graphite for lining the puddling vessel; he had tried ground coke and tar, but with only very partial success, and had therefore abandoned the idea of looking any further in that direction. The experiments he feared had exhausted almost every material that appeared likely to succeed; but now that general attention was directed to the subject he hoped something might ultimately be devised which would answer the required purpose.

Mr. C. Cochrane enquired whether any objection was found in practice from the heat that would issue at the open mouth of the firebox, when the puddling vessel was removed from the driving machinery on the completion of working a charge.

Mr. Menelaus explained that no difficulty was experienced in that respect, because the only draught upon the fire was that produced through the puddling vessel and the fluebox by the chimney which created the draught; and as there was no longer any draught upon the fire when the puddling vessel was removed, no emission of flame took place at that time from the open mouth of the firebox; and no inconvenience was experienced from the heat in standing within two or three feet of the open firebox mouth.

The President enquired whether the balls produced from the puddling vessel were hammered or squeezed; and he asked what was the object of the unsymmetrical form given to the two ends of the vessel, as shown in the drawing.

Mr. Menelaus said that the balls produced from the puddling vessel were all hammered under the steam hammer in the forge. In the original experimental puddling vessel the two ends were made symmetrical (as shown by the dotted lines in Fig. 6); but the subsequent vessels had been made with unsymmetrical ends, having a bulge at each end, for the purpose of giving the fluid iron an end motion during the rotation of the vessel, with the idea of ensuring a more thorough working of the iron. Experience had shown however that this was not necessary in practice, and that the original shape with symmetrical ends was preferable; and it had the advantage of being simpler for construction and lining, as the transverse section was then a true circle in all parts.

Mr. W. E. Newton mentioned that a plan of horizontal puddling furnace had been proposed, having a revolving bottom carried upon an axis slightly inclined to the vertical, so as to convert the rotary movement into something like a rocking motion of the furnace bottom, in order to make the ball roll about during the puddling. He enquired whether any attempts had been made at Dowlais to employ a rocking motion, instead of the rotary motion of the revolving puddling vessel.

Mr. MENELAUS replied that he had not tried a rocking motion, except so far as that sort of movement was produced by the unsymmetrical ends of the revolving puddling vessel; but he found the simple rotary motion produced quite sufficient effect in working the iron in the vessel, and he considered this plan was most likely to prove ultimately successful. In the first experiments he had also tried reversing the motion of the puddling vessel about every two minutes, making a dozen revolutions in one direction, and then a dozen back again; but this was not found to be any improvement over the simpler plan of driving the vessel continuously in the same direction.

The PRESIDENT enquired what had been the practical success up to the present time in the working of the other methods which had been tried for effecting mechanical puddling, without having recourse to a rotary motion.

Mr. MENELAUS replied that the machine invented in France some years ago for working the ordinary puddling tool or rabble in the ordinary furnaces had been introduced into England, and applied by Mr. Bennett to the puddling furnaces at the Wombridge Iron Works, Shropshire, as described by him at a former meeting of the Institution (see Proceedings Inst. M. E. 1864, page 298); and great credit was due to Mr. Bennett for the ingenuity he had displayed in simplifying and improving the machinery. The plan however had not been taken up extensively elsewhere. The object in that case was to do away with the severe labour of puddling, by performing the rabbling action by mechanical means, leaving the puddler to exercise only his skill in controlling the operation; and he believed the plan was a great success as far as it went, but he thought it did not go far enough, as it did not ball up the iron at the completion of the puddling. His own object was to do away with the puddler's labour altogether, so as to enable one skilled workman to manage three or four furnaces simultaneously. Where great skill and great bodily labour were required in combination, high wages were inevitable; and unless some scheme could be devised for doing away with the hard work in puddling, he did not know where men enough would be got to perform the work, or how the manufacture of iron would ultimately be carried on.

Mr. E. Riley mentioned that there was also another machine by Mr. Griffiths of Derby, for working the ordinary puddler's rabble, which had been employed at the Milton and Elsecar Iron Works near Barnsley; but at these works he understood the machines had not found favour with the men, and when it was at length left to the option of the men whether the machines should be used or not, they had preferred not to use them, except for working grey iron, which involved the severest labour in puddling. At the Tow Law Iron Works near Darlington another description of puddling machine for the same object had been tried, and the men had the option of using it, but seldom did so.

Mr. E. Williams remarked that even if only the rabbling of the metal in the ordinary puddling furnace were done by machinery, that would be an important advantage; for the greatest skill and labour of the puddler were required when the balling up commenced, at which time in the ordinary process his strength was nearly exhausted by the previous puddling.

Mr. F. W. Webb mentioned that he was working at Bolton one of Mr. Siemens' regenerative puddling furnaces; and although the puddling was still done by manual power, there was a considerable saving of labour to the men, as shown by the fact that three shifts of 8 hours each were made every 24 hours, each shift consisting of six heats, and each heat taking on an average 70 minutes; whereas in the old furnaces two shifts of 12 hours each per 24 hours were about the average, each shift consisting of six heats. The great advantage of the regenerative furnace for puddling was that it gave the means of obtaining any temperature or flame that was wanted, and was most perfectly under control; and it effected a considerable saving in fuel.

Mr. W. M. Neilson observed that the plan of mechanical puddling described in the paper was evidently not the result merely of a lucky idea, but had been carefully worked out by Mr. Menelaus under the pressure of necessity, in the long series of experiments of which he had now given them the particulars; and although he had not yet completely succeeded in the object aimed at, they were equally indebted to him for his labours, and could well understand how great his exertions had been. At the present time it was indeed discreditable to so splendid a manufacture as that of iron, that it was dependent upon the class of labour which was required in puddling; but now that so much attention was being directed to this subject, he trusted this particular department of the iron manufacture would not long continue in its present state; and he was sure the further efforts of Mr. Menelaus in the direction of mechanical puddling would be watched with the liveliest interest.

The PRESIDENT considered they were greatly indebted to Mr. Menelaus for the perseverance and talent he had displayed in striving to carry out the system of mechanical puddling now described; and hoped he would not relax his efforts in endeavouring to attain the important object in view. There was no heavier kind of work than that of the puddler, for which consequently it was necessary to pay very dearly; and it was therefore highly desirable to lessen the amount of that labour, and leave the puddler to look on and exercise his skill only in the control of the process.

He moved a vote of thanks to Mr. Menelaus for his paper, which was passed.

The Meeting was then adjourned to the following day.

The Adjourned Meeting of the Members was held in the Lecture Theatre of the Conservatoire Impérial des Arts et Métiers, Paris, on Thursday, 6th June, 1867; JOHN PENN, Esq., President, in the Chair.

The following paper was read:—

ON THE MACHINERY FOR BORING ARTESIAN WELLS.

By M. DRU, of Paris.

The Artesian Wells at present sunk in the tertiary formation of the Paris basin, Fig. 34, Plate 47, range in size generally from about 8 inches down to 2 inches diameter, with a depth of about 230 to 350 feet. The bore-hole is usually lined with copper, in order to make the wells water-tight and bring the water to the surface without loss. These works often present considerable difficulties in their execution, from the frequent changes in the nature of the ground passed through, and from the impediments that are so often encountered in driving the tubes through the beds of sand and clay.

Borings of a much greater depth and larger size are now in process of execution in Paris, for the purpose of bringing to the surface a large supply of the artesian waters from the lower green sand underlying the chalk in the secondary formation; the existence of a supply of water in that stratum has already been proved by the well sunk at Grenelle of 3¾ inches diameter, which was finished in 1841, and the subsequent one of 27½ inches diameter sunk at Passy, and finished in 1861. Each of these two artesian wells required 6 or 7 years' work for its completion; their situation in Paris is shown in the plan, Fig. 36, Plate 49.

A large artesian well is now being constructed by the writer at Butte-aux-Cailles, Fig. 36, for the supply of the city of Paris, which is intended to be carried down through the green sand to a depth of 2600 or 2900 feet to reach the Portland limestone. The boring is at present 490 feet deep, and its diameter is as large as 47 inches.

During the last 2½ years the writer has also been sinking a similar well of 19 inches diameter for supplying the Sugar Refinery of M. Say, in Paris, Fig. 36; this well is now 1570 feet deep, Fig. 39, and it is expected that the water-bearing strata will be reached at a depth of about 1800 feet.

For the smaller wells, hand-boring tools are in use; but these are limited to borings of inconsiderable depth and small diameter. For borings of the diameter of these large wells, it is necessary to make use of special tools, worked entirely by steam power; and in some cases of sinking mine shafts, tools of as large a diameter as 14¼ feet have been used. The boring is effected by a rotary motion in the case of the small diameters; but in borings of a large diameter and considerable depth, percussive action alone is employed, which is effected by raising the tool and letting it fall with successive strokes.

The apparatus employed by the writer in boring the large wells that have been mentioned is shown in Figs. 1 and 2, Plates 39 and 40. The boring rod A is suspended from the outer end of the working beam B, which is made of timber hooped with iron, working upon a middle bearing, and is connected at the inner end to the vertical steam cylinder C of 10 inches diameter and 39 inches stroke. The stroke of the boring rod is reduced to 22 inches, by the inner end of the beam being made longer than the outer end, serving as a partial counterbalance for the weight of the boring rod. The steam cylinder is shown enlarged in Fig. 3, and is single-acting, being used only to lift the boring rod at each stroke, and the rod is lowered again by releasing the steam from the top side of the piston; the stroke is limited by timber stops both below and above the end of the working beam B.

The Boring Tool is the part of most importance in the apparatus, and the one that has involved most difficulty in maturing its construction. The points to be aimed at in this are,—simplicity of construction and repairs,—the greatest force of blow possible for each unit of striking surface,—and freedom from liability to get turned aside and choked.

The tool used in small borings is a single chisel, as shown in Figs. 21 and 22, Plate 44; but for the large borings it is found best to divide the tool-face into separate chisels, each of convenient size and weight for forging. All the chisels however are kept in a straight line, whereby the extent of striking surface is reduced; and the tool is rendered less liable to be turned aside by meeting a hard portion of flint on a single point of the striking edge, which would diminish the effect of the blow.

The tool is shown in Figs. 23 to 29, Plates 44 and 45; and is composed of a wrought-iron body D, connected by a screwed end E to the boring rod, and carrying the chisels F F fixed in separate sockets and secured by nuts above; two or four chisels are used, or sometimes even a greater number, according to the size of the hole to be bored. This construction allows of any broken chisel being easily replaced; and also by changing the breadth of the two outer chisels, the diameter of the hole bored can be regulated exactly as may be desired. When four chisels are used, the two centre ones are made a little longer than the others, as shown in Fig. 27, to form a leading hole as a guide to the boring tool. A crossbar G, of the same width as the tool, guides it in the hole in the direction at right angles to the tool; and in the case of the larger and longer tools a second crossbar is also added higher up, at right angles to the first and parallel to the striking edge of the tool.

If the whole length of the boring rod were allowed to fall suddenly to the bottom of a large bore-hole at each stroke, frequent breakages would occur; it is therefore found requisite to arrange for the tool to be detached from the boring rod at a fixed point in each stroke, and this has led to the general adoption of *free-falling tools*. There have been several contrivances for effecting this object, and the writer's plan of self-acting free-falling tool, liberated by reaction, is shown in side and front view in Figs. 12 and 13, Plate 42. The hook H, attached to the head of the boring tool D, slides vertically in the box K, which is screwed to the lower extremity of the boring rod; and the hook engages with the catch J centred in the sides of the box K, whereby the tool is lifted as the boring rod rises. The tail of the catch J bears against an inclined plane L at the top of the box K, and the two holes carrying the centre pin I of the catch are made oval in the vertical direction so as to allow a slight vertical movement of the catch. When the boring rod reaches the top of the stroke, it is stopped suddenly by the tail end of the beam B, Fig. 2, striking upon the wood buffer-block E; and the shock thus occasioned causes a slight jump of the catch J in the box K; the tail of the catch is thereby thrown outwards by the incline L, as shown in Fig. 14, liberating the hook H, and the tool then falls freely to the bottom of the bore-hole, as shown in Fig. 15. When the boring rod descends again after the tool, the catch J again engages with the hook H, enabling the tool to be raised for the next blow, as in Fig. 13.

Another construction of self-acting free-falling tool, liberated by a separate disengaging-rod, is shown in side and front view in Figs. 16 and 17, Plate 43. This tool consists of four principal pieces, the hook H, the catch J, the paul I, and the disengaging-rod M. The hook H, carrying the boring tool D, slides between the two vertical sides of the box K, which is screwed to the bottom of the boring rod; and the catch J works in the same space upon a centre pin fixed in the box, so that the tool is carried by the rod, when hooked on the catch, as shown in Fig. 17. At the same time the paul I at the back of the catch J secures it from getting unhooked from the tool; but this paul is centred in a separate sliding hoop N forming the top of the disengaging-rod M, which slides freely up and down within a fixed distance upon the box K; and in its lowest position the hoop N rests upon the upper of the two guides P P, Fig. 16, through which the disengaging-rod M slides outside the box K. In lowering the boring rod, the disengaging-rod M reaches the bottom of the bore-hole first, as shown in Figs. 16 and 17, and being then stopped, it prevents the paul I from descending any lower; and the inclined back of the catch J sliding down past the paul, the latter forces the catch out of the hook H, as shown in Fig. 18, thus allowing the tool D to fall freely and strike its blow. The height of fall of the tool is always the same, being determined only by the length of the disengaging-rod M.

The blow having been struck, and the boring rod continuing to be lowered to the bottom of the hole, the catch J falls back into its original position, and engages again with the hook H, as shown in Fig. 19, ready for lifting the tool in the next stroke. As the boring rod rises, the tail of the catch J trips up the paul I in passing, as shown in Fig. 20, allowing the catch to pass freely; and the paul before it begins to be lifted returns to the original position shown in Fig. 17, where it locks the catch J, and prevents any risk of its becoming unhooked either in raising or lowering the tool in the well.

The boring tool shown in Figs. 23 to 25, Plate 44, which is employed in boring the well of 19 inches diameter at the Sugar Refinery, weighs $\frac{3}{4}$ ton and is liberated by reaction, by the arrangement shown in Plate 42; and the same mode of liberation was applied in the first instance to the larger tool shown in Plate 45, employed in sinking the well of 47 inches diameter at Butte-aux-Cailles. The great weight of the latter tool however, amounting to as much as $3\frac{1}{2}$ tons, necessitated so violent a shock for the purpose of liberating the tool by reaction, that the boring rods and the rest of the apparatus would have been damaged by a continuance of that mode of working; and the writer was therefore led to design the arrangement of disengaging-rod for releasing the tool, as shown in Plate 43. This mode of liberation is consequently the one now in use at Butte-aux-Cailles, where it has proved completely successful in practical working. In this case the cross guide G fixed upon the tool is made with an eye for the disengaging-rod M to work through freely, as shown in Figs. 26 and 28. For borings of small diameter however the disengaging-rod cannot supersede the reaction system of liberation, as the latter alone is able to work in borings as small as $3\frac{1}{4}$ inches diameter; and a bore-hole no larger than this diameter has been successfully completed by the writer with the reaction tool to a depth of 750 feet.

The boring rods employed are of two kinds, wrought-iron and wood. The wood rods, shown in Figs. 2 and 4, are used for borings of large diameter, as they possess the advantage of having a larger section for stiffness without increasing the weight; and also when immersed in water the greater portion of their weight is floated. The wood for the rods requires to be carefully selected, and care has to be taken to choose the timber from the thick part of the tree, and not the toppings; in France, Lorraine or Vosges deals are preferred.

The boring rods, whether of wood or iron, are screwed together either by solid sockets, as in Fig. 6, Plate 41, or with separate collars, as in Fig. 7. The separate collars are preferred for the purpose, on account of being easier to forge; and also because, as only one-half of the collar works in coupling and uncoupling the rods, while the other half is fixed, the screw thread becomes worn only at one end, and by changing the collar end for end a new thread is obtained when one is worn out, the worn end being then jammed fast as the fixed end of the collar.

The boring rod is guided in the lower part of the hole by a lantern R, Fig. 2, shown to a larger scale in Figs. 4 and 5, which consists of four vertical iron bars curved in at both ends, where they are secured by moveable sockets upon the boring rod, and fixed by a nut at the top. By changing the bars the size of the lantern is readily adjusted to any required diameter of bore-hole, as indicated by the dotted lines. In raising up or letting down the boring rod, two lengths of about 30 feet each are detached or added at once, and a few shorter rods of different lengths are used to make up the exact length required. The coupling screw S, Fig. 2, by which the boring rod is connected to the working beam B, serves to complete the adjustment of length; this is turned by a cross bar, and then secured by a cross pin through the screw.

In ordinary work, breakages of the boring rod generally take place in the iron, and more particularly at the part screwed, as that is the weakest part. In the case of breakages, the tools usually employed for picking up the broken ends are a conical screwed socket, shown in Fig. 9, Plate 41, and a claw, shown in Fig. 8. Tools with nippers are sometimes used in large borings, as it is not advisable to subject the rods to a twist.

When the boring tool has detached a sufficient quantity of material, the boring rod and tool are drawn up by means of the rope O, Fig. 1, Plate 39, winding upon the drum Q, which is driven by straps and gearing from the steam engine T. A scoop is then lowered into the bore-hole by the wire rope U from the other drum V, and is afterwards drawn up again with the excavated material. A friction break is applied to the drum Q, for regulating the rate of lowering the boring rod down the well. The scoop, shown in Figs. 31 and 32, Plate 46, consists of a rivetted iron cylinder, with a handle at the top which can either be screwed to the boring rod or attached to the wire rope; and the bottom is closed by a large valve opening inwards. Two different forms of valve are used, either a pair of flap valves, as shown in Fig. 31, or a single cone valve, Fig. 32; and the bottom ring of the cylinder, forming the seating of the valve, is forged solid and steeled on the lower edge. On lowering this cylinder to the bottom of the bore-hole, the valve opens and the loose material enters the cylinder, where it is retained by the closing of the valve, whilst the scoop is drawn up again to the surface. In boring through chalk, as in the case of the deep wells in the Paris basin, Fig. 34, Plate 47, the hole is first made of about half the final diameter for 60 to 90 feet depth, and it is then enlarged to the full diameter by using a larger tool. This is done for convenience of working, for if the whole area were acted upon at once, it would involve crushing all the flints in the chalk; but by putting a scoop in the advanced hole, the flints that are detached during the working of the second larger tool are received in the scoop and removed by it, without getting broken by the tool.

The resistance experienced in boring through different strata is very various, and some rocks passed through are so hard that with 12,000 blows per day of a boring tool weighing nearly 10 cwts., with 19 inches height of fall, the bore-hole was advanced only 3 to 4 inches per day. As the opposite case, strata of running sand have been met with so wet that a slight movement of the rod at the bottom of the hole was sufficient to make the sand rise 30 to 40 feet in the bore-hole. In these cases the writer has adopted the Chinese method of effecting a speedy clearance, by means of a scoop closed by a large ball clack at the bottom, as shown in Fig. 30, Plate 46, and suspended by a rope, to which a vertical movement is given; each time the scoop falls upon the sand a portion of this is forced up into the scoop, and retained there by the ball valve.

An artesian well is always some time in settling down to its permanent working state, generally one or two months; and when the water first reaches the surface it undergoes considerable fluctuations, being charged from time to time with the substances at the bottom of the bore-hole. In the Grenelle well there were fluctuations at starting of 300 feet in the height of the water. The velocity of the flow of water from the artesian wells varies considerably, and the following are some examples of the delivery at the surface by those already completed in the Paris basin:—

	Depth of Bore-hole. Feet.	Diameter of Bore-hole. Inches.	Gallons delivered per minute.	Velocity of discharge. Feet per second.
St. Denis, Hôtel Dieu	262	2·28	28	2·68
Gennevilliers	312	2·28	31	2·89
Stains	266	2·95	176	9·87
Elbeuf	492	2·95	66	3·71
Paris, Grenelle	1795	3·74	484	16·63
„ Passy	1923	27·56	1980	1·64

The localities of these wells are shown in the plans, Figs. 35 and 36, Plates 48 and 49; and Fig. 34, Plate 47, is a geological section passing through the Paris basin, taken along the course of the dotted line in Fig. 35 from Niort to Verdun. Sections of the strata bored through in the wells at Passy and Grenelle are shown in Figs. 37 and 38, Plate 49; and Fig. 39 is the section in the boring now in progress at the Sugar Refinery. In the case of the artesian well at Grenelle, the water is carried up to a height of 128 feet above the ground by a stand-pipe of 3·74 inches bore, from the top of which the water overflows at the rate of 100 gallons per minute with a velocity of 3·94 feet per second.

Borings of large diameter for mines or other shafts are also sunk by means of the same description of boring tools, only considerably increased in size, extending up to as much as 14 feet diameter. The well is then lined with cast-iron or wrought-iron tubing, for the purpose of making it water-tight; and a special contrivance invented by M. Kind has been adopted for making a water-tight joint between the tubing and the bottom of the well, or with another portion of tubing previously lowered down. This is done by a stuffing-box, shown in Fig. 33, Plate 46, which contains a packing of moss at AA. The upper portion of the tubing is drawn down to the lower portion by the tightening screws BB, so as to compress the moss packing when the weight is not sufficient for the purpose. A space C is left between the tubing and the side of the well, to admit of the passage of the stuffing-box flange, and also for running in concrete for the completion of the operation. The moss packing rests upon the bottom flange D, but this flange is sometimes omitted. The joint is thus simply made by pressing out the moss packing against the sides of the well; and this material, being easily compressible and not liable to decay under water, is found to make a very satisfactory and durable joint.

M. Dru exhibited specimens of the various boring tools described in the paper, and also working models of the two plans of liberating the tool, by reaction and by a disengaging-rod, showing the mode of disengaging the tool in each case. He stated that the reaction tool had been successfully employed for borings up to as large as about 4 feet diameter, as in the case of the well now sinking at Butte-aux-Cailles of 47 inches diameter; but beyond that size he thought the shock requisite to liberate the larger and heavier tool would probably be so excessive as to be injurious to the boring rods and the rest of the attachments; and he had therefore designed the arrangement of the disengaging-rod for liberating the tool in borings of large diameter, whereby all shock upon the boring rods was avoided and the tool was liberated with complete certainty. He was now employing this mode of liberation in place of the reaction plan in the boring at Butte-aux-Cailles, where the weight of the falling tool was as much as 3½ tons; as he thought the shock necessary to liberate so heavy a tool by the reaction method would prove detrimental to the rest of the apparatus. In this case also the diameter of the well was going to be increased to 71 inches, when the total weight of the falling tool would be upwards of 5 tons. The disengaging-rod had further the advantage mentioned in the paper, that there was no risk of the tool getting accidentally liberated by any jerk in lowering the boring rods and tool down the well after they had been drawn out for any purpose.

He explained that it was necessary to turn the boring tool partly round between each stroke, so as to prevent it from falling every time in the same position at the bottom of the well; and this was effected by manual power at the top of the well, by means of a long hand lever fixed to the boring rod by a clip bolted on, which was turned round by a couple of men through part of a revolution during the time that the tool was being lifted. The turning was ordinarily done in the right-hand direction only, so as to avoid the risk of unscrewing any of the screwed couplings of the boring rods; and care was taken to give the boring rod half a turn when the tool was at the bottom, so as to tighten the screw couplings, which otherwise might shake loose. In the event of a fracture however, leaving a considerable length of boring rod in the hole, it was sometimes necessary to have the means of unscrewing the couplings of the portion left in the hole, so as to raise it in parts instead of all at once. In that case a locking clip was added at each screwed joint above, and secured by bolts, as shown at C in Figs. 10 and 11, Plate 41, at the time of putting the rods together for lowering them down the well to recover the broken portion; and by this means the ends of the rods were prevented from becoming unscrewed in the coupling sockets, when the rods were turned round backwards for unscrewing the joints in the broken length at the bottom of the bore-hole.

Mr. J. Lancaster enquired what was the average cost of boring any of the ordinary bore-holes in the Paris basin by the system described in the paper.

M. Dru replied that it was impossible to state any amount as an average of the cost, because the circumstances varied so much at the different wells sunk in the Paris basin, in regard to the thickness and hardness of the strata passed through, as well as the size and depth of the bore-hole, that the cost of the boring was not at all similar in any two cases. Thus the cost of the two wells described in the paper as now in process of sinking at M. Say's works and at Butte-aux-Cailles, both being on the southern side of Paris, would probably amount to as much as £12,000 and £20,000 respectively when the wells were completed, exclusive of the tubing for lining, the diameters of the bore-holes being 19 inches and 47 inches, and the contemplated depths

1800 feet and 2600 feet respectively. On the other hand a well sunk at St. Denis, six miles north of Paris, had cost only £280 including the copper lining, the depth being about 260 feet and the diameter 4¾ inches; and at Enghien-les-Bains, also about six miles north of the city, a boring of 9¾ inches diameter had been sunk to a depth of 82 feet for only £12, the first water-bearing stratum being reached at a depth of only 20 to 23 feet. In this case the well was lined with 2⅜ inch thickness of wood, reducing the internal diameter to 5 inches; and a wood lining was sometimes preferred to wrought-iron or cast-iron tubing, according to the nature of the ground passed through.

Mr. J. **Lancaster** remarked that in boring for coal a bore-hole of 3 inches diameter had been put down in Nottinghamshire, with which he had been connected, and it had been carried to a depth of 1050 feet at a cost of £3000. In another bore-hole of 3 inches diameter that he had sunk lately for coal near Wigan, and had carried to a depth of 1200 feet, he had found the cost of sinking to be about £100 for the first 300 feet, £400 for the second, £1600 for the third, and £3200 for the last 300 feet, making a total cost of £5300 for the whole depth of 1200 feet. If in each case the Belgian system of M. Kind with a hollow annular tool had been employed, it would have had the great advantage of bringing up the core of the hole, whereby a series of cores would have been obtained, forming a complete and accurate vertical section of the stratification in the boring throughout the entire depth from top to bottom of the bore-hole.

Mr. C. **Cochrane** suggested that the amount of the working expenses per day in boring by the system described in the paper would afford the means of estimating the cost of a bore-hole of any depth, according to the hardness of the strata to be passed through and the consequent rate of progress per day. It appeared from the paper that in boring through very hard rock the progress had been only 3 or 4 inches per day; and no doubt the rate of progress was pretty well ascertained in the case of other materials also.

M. **Dru** said that the cost of boring through any particular stratum, such as sand or clay or granite, could of course be given approximately; but even then such statements were frequently invalidated altogether by the delays consequent upon breakages; and in some instances his own experience of boring had been that, owing to the difficulties attending the operation, the occurrence of delays from accidents was the rule, while the regular working of the machinery was the exception. He exhibited specimens of the different modifications of boring tools which he had found most efficacious for passing through the different strata met with in the Paris basin; and explained that, although the chisel-shaped tools described in the paper were the form principally employed, he considered it would be a mistake to attempt to use any one form of tool exclusively for all descriptions of ground. For passing through granite or any other primary rock a percussive action was indispensable, and the force of the blow was required to be concentrated upon a small extent of cutting edge, in order to produce any effect by the blow; but in softer ground a greater number of cutting chisels were used in the falling tool.

Mr. W. **Mather** considered they were much indebted to M. Dru for the interesting details given in the paper of the system of boring employed in sinking the artesian wells in Paris; a large amount of courage and perseverance had certainly been shown in carrying down the borings to the great depths necessary for procuring the water from the green sand, and he was much struck with the important results obtained from the wells of which the particulars had been given. The main principle which appeared to characterise the plans of boring employed in France was that the boring tool was worked entirely by rods, throughout the whole depth from the surface to the bottom of the bore-hole; and consequently when borings of any considerable depth were attempted, the rods became so heavy that breakages would occur if the rods were allowed to fall with the tool at each stroke. The system of free-falling tools was therefore introduced, for allowing the tool to fall free of the rods; and two very ingenious arrangements of liberating gear for this purpose had been described in the paper. In England however, in the case of boring for the purposes of coal pits or for obtaining water supply for towns, the rod system, although not entirely abandoned, was carried out in a very rude manner, far inferior to that adopted in France according to the description furnished by the paper. This was owing he believed to the great difficulties which had been experienced in applying rods to borings of a large size; and accordingly a flat wire or hemp rope, 5 inches broad and ½ inch thick, was now being used, which was passed over head-gear at the top of the bore-hole, like the ordinary winding ropes at collieries, and was worked by a direct-acting steam cylinder to give the blow. This arrangement, by dispensing with the rods, allowed of making the boring tools much simpler than those used in France, avoiding the necessity for liberating the tool from the rope for each fall and then attaching it again for raising. The tool that had been used for all descriptions of borings consisted simply of a plain bar of Bessemer steel, about 6 or 8 feet long, carrying a cast-iron block at the bottom end, which was perforated with a number of holes to receive the boring chisels or cutters; these were of different shapes according to the nature of the strata to be bored through. With this tool worked by the flat rope, bore-holes of 15 inches to 24 inches diameter had been sunk, the weight of the tool being about 1 ton. The same tool had been used with equal success for boring through the tertiary strata or through primary rock; in the latter case the height of fall was increased as found requisite up to as much as 8 feet. He enquired whether there had been any experience in France of the use of ropes for working the boring tools, and what was the reason for preferring rods for the purpose.

M. Dru replied that as long ago as 1842 ropes had been used in France for boring purposes, but they had not been found to answer in boring through clay, because the tool got choked and stuck fast, and the rope broke, leaving the tool imbedded at the bottom of the bore-hole; it was then necessary to have recourse to rods for raising the boring tool, and he therefore preferred to use rods in the first instance. In boring through sand however ropes had been successfully employed, and by this means borings had been carried down with great rapidity, as much as 60 feet depth having been accomplished in a fortnight through a bed of sand in boring a well in the upper stratum of the Paris basin. The section of the Paris basin showed that, owing to the variable strata to be passed through, no one form of boring tool such as had been referred to could be used for all parts of the bore-hole, but different tools were required according to the particular stratification at the bottom of the hole.

Mr. W. **Mather** remarked that the objections which were stated to have attended the use of ropes for boring purposes in France had not been experienced in England, where ropes had been successfully employed in sinking borings through all descriptions of ground, including running sands, clay, and beds of the hardest chalk interspersed with flints. In a boring lately executed near Norwich with the rope apparatus to a depth of 1200 feet, having a diameter of 20 inches in the upper part and 18 inches below, all these varieties of stratification had been successfully passed through, without any failure occurring of the rope working the boring tools; and he did not see how objections could arise to the employment of the same system of boring in France.

Mr. W. **Clay** mentioned that in putting down a bore-hole of 8 inches diameter to a depth of 230 feet through the sandstone rock at Liverpool, for the purpose of obtaining water, he had used a tool somewhat different from those now exhibited, more like an ordinary drill with cutters round it, and similar to a boring bar for boring out cylinders &c. This was worked by a hemp rope passing over headgear from a drum on the steam-engine shaft, and the drum was connected to the shaft by a friction clutch, so as to liberate the rope for the fall of the tool. This plan had proved very satisfactory in rapidity of progress, and he had not had any difficulties, the boring being only through the sandstone rock for the whole depth.

Mr. F. J. **Bramwell** enquired whether there was not a liability, in the case of the reaction tool, that the tool might fail to liberate itself from the boring rod at the top of the stroke, either by the liberating catch getting choked with dirt, or by the friction of the tool in the bore-hole being so great as to prevent the slight jump at the top of the stroke which was necessary for releasing the tool in that plan of disengaging.

He asked also, in regard to the difference in the rapidity of flow of the water from the several wells referred to in the paper, what was the height to which the water would rise in a tube continued upwards above the surface of the ground; and whether any difference in that level was occasioned by sinking the well deeper.

M. Dru replied that he had not experienced any difficulty in the liberation of the reaction tool; the catch was made so heavy that it always fell back immediately into the vertical position after liberating the tool, and it had never been found to become gagged with dirt, being placed always at a considerable height above the bottom of the well; at Butte-aux-Cailles this height was as much as 23 to 26 feet. On account of the great weight and momentum of the rising tool, in comparison with the small extent of the rubbing surface against the sides of the hole in rising, the friction was not sufficient to interfere at all with the liberation of the tool by the shock on reaching the top of the stroke. Moreover the chisels at the bottom of the tool projected laterally beyond the body of the tool itself, as seen in Figs. 24 and 27, so that the only surface rubbing against the sides of the bore-hole was the edge of the chisel, of about 3 to 6 inches width.

With regard to the delivery of water obtained from the artesian wells, the quantity was not always proportionate to the area of the bore-hole in any particular situation; and as to the height to which the water would rise, and the velocity of delivery, it was impossible to arrive at any rule generally applicable to the delivery of artesian wells. The results in any particular case depended upon the abundance of the supply yielded by the water-bearing strata, the permeability of the soil, and the level of the surface of the ground at the mouth of the well. It was therefore impossible to make any comparison between the wells sunk in Paris, and those for example at St. Denis in the immediate neighbourhood. The latter were sunk only in the tertiary formation, to depths varying from 230 to 350 feet below the surface of the ground; the first water-bearing stratum was met with at 200 to 210 feet depth, and the extreme height to which the water rose was 327 feet above the level of the sea, or 237 feet above the surface of the ground in that locality. The Grenelle and Passy wells in Paris, on the other hand, were carried down below the chalk in the secondary formation, that at Grenelle to the depth of 1795 feet below the surface of the ground, or 1673 feet below the level of the sea; the water rose at Grenelle to a height of 128 feet above the ground, and as the delivery at that height was 100 gallons per minute, it was considered that if the pipe were continued upwards the water would rise as much as 80 to 140 feet higher. It was thus evident that there was no ground for comparison between artesian wells sunk under different circumstances as to locality and depth.

Mr. W. **Fairbairn** observed that from the particulars given in the paper the quantity of water delivered by the artesian wells sunk in the Paris basin seemed so small in proportion to the depth of the borings and the time and labour expended upon their execution, that it appeared to him questionable whether the result would be found to justify the necessary outlay, in any situations where there were opportunities of procuring the requisite water supply by other means. In reference to the mode of sinking, he thought the description that had been given of the various tools employed and of the mode of working was of much practical value in connection with borings generally.

Mr. C. **Cochrane** enquired whether any of the beds of sand passed through by the boring tools described in the paper had been running sands; and what special means had been employed for shutting off a running sand, in order to enable the work to be proceeded with.

M. **Dru** replied that running sands had been met with in several of the bore-holes which he had put down; and the plan he had adopted was to use the Chinese ball-scoop described in the paper for clearing the bottom of the bore-hole; and where there was too much sand for it to be got rid of in that way, a tube had to be sent down from the surface to shut off the sand. This of course necessitated diminishing the diameter of the hole in passing through the sand; but on reaching the solid rock below the running sand, an expanding tool was used, for continuing the bore-hole below the tubing with the same diameter as above it, so as to allow the tubing to go down with the hole.

Mr. R. **Mallet** remarked that one of the most serious difficulties which could be encountered in boring was where an inclined surface of hard rock was met with, intersecting the boring at a very considerable inclination. In the case of a boring executed at Ibbenburen in Westphalia, a large block of red hæmatite mixed with quartz was encountered, imbedded in marl, which met the boring tool at an inclination of as much as about 70° from the horizontal. This proved a very serious barrier to the progress of the hole; for although the length of the guided part of the tool was about 8 feet, while the diameter of the hole was only a few inches, the tool could not be kept straight, but was turned aside, and the hole consequently became cavernous and crooked at that part. He enquired how such a difficulty as this would be met in the system of boring described in the paper.

M. **Dru** exhibited a specimen of the tool that was used in the case of meeting with a surface of very hard rock at a considerable inclination to the bore-hole, the cutters being fixed in a circle all round the edge of the tool, instead of in a single diameter line; the length of the tool was also considerably increased in that instance, as compared with the tools used for ordinary work, so that it was guided for a length of as much as 20 feet. He stated that he used this tool in all cases where from any cause the hole was found to be going crooked; and he had even succeeded by this means in straightening a hole that had previously been bored crooked. The cutting action of this tool was all round its edge; and therefore in meeting with an inclined hard surface, as there was nothing to cut on the lower side, the force of the blow was brought to bear on the upper side alone, until an entrance was effected into the hard rock in a true straight line with the upper part of the hole.

Mr. R. **Mallet** mentioned that in the boring at Ibbenburen that he had referred to, which was done with wooden boring rods, the couplings of the rods were made of steel instead of iron; and he thought it was preferable to use steel for the purpose, as it appeared from the statement in the paper that with the iron couplings the breakages which occurred of the boring rods generally took place at the couplings, more particularly at the screwed part, which was of course the weakest point.

M. **Dru** said he had not used steel for the couplings of the boring rods; for though the breakages generally occurred in the iron, he had not considered that they were sufficiently frequent or serious to justify the substitution of steel couplings. He exhibited the conical screwed sockets that were used in the event of a breakage for raising the broken rods left in the bore-hole, one of the sockets being made with an ordinary V thread for the cases where the breakage occurred in the iron; while the other socket having a sharper thread, like a wood screw, was intended for use when the breakage was in one of the wood rods. In order to ascertain the shape of the fractured end left in the bore-hole, and its position relatively to the centre line of the hole, he explained that a similar conical socket was first lowered, having its under surface filled up level with wax, so as to take an impression of the broken end, and show what size of screwed socket should be employed for getting it up. He showed also the conical screwed plug that was used for bringing up or letting down the metal tubes employed for lining the bore-holes; and also specimens of the tubes of different sizes used for the purpose. The larger tubes, above 6 feet diameter, were of cast iron, the several lengths being connected together by internal flange joints bolted together; below that size, rivetted wrought-iron tubes were used, or copper tubes with screwed socket joints. He explained that in raising the boring rods they were generally uncoupled at every alternate coupling only, when the hole had been sunk to some depth below the surface, so as to save time by avoiding the necessity of uncoupling every joint; and the timber shed erected over the mouth of the hole was carried up to a sufficient height to take in the double lengths of rods without uncoupling, amounting to 65 feet length.

The PRESIDENT moved a vote of thanks to M. Dru, which was passed, for his paper, and for the very complete and interesting collection which he had exhibited of the various tools employed in the borings that he had executed.

He mentioned that the Members would have the opportunity on the following day of visiting the works of the borings now in progress of execution by M. Dru in Paris, at Butte-aux-Cailles and at M. Say's sugar refinery.

The following paper was then read:—

ON THE STEAM DREDGERS EMPLOYED IN THE EXCAVATION OF THE ISTHMUS OF SUEZ CANAL.

BY M. BOREL, OF PARIS.

The excavation of the Suez Canal is not of the same character throughout, the general configuration of the Isthmus requiring at one part cuttings of considerable depth; but the greater portion of the length requires only the excavation of a channel through ground scarcely above the sea level, and a considerable portion lies below that level so as to require embanking on each side of the channel. A general plan and section of the entire Canal is shown in Figs. 1 and 2, Plate 50. The present distance from the Mediterranean to the Red Sea across the Isthmus of Suez is 100 miles; but at a comparatively recent date the waters of the Mediterranean reached up to the table-land of El Ferdane, and the Red Sea nearly to Chalouf. The land distance of 56 miles between these places was further reduced by Lake Timsah, which was formerly fed by the waters of the Nile, having a bottom 19 feet below the sea level; and also by the two Bitter Lakes, which are 12½ and 9 miles length, and 16 to 32 feet depth below the sea level, but are at the present time dry. The Mediterranean thus appears to have retreated about 37 miles, leaving behind it the shallow lakes or rather marshes of Lake Ballah and Lake Menzaleh, from the latter of which it is now separated by a narrow belt of sand of only 100 to 200 yards width. The Red Sea has also retreated about 9 miles, leaving a plain at nearly the level of high tide.

The first half of the entire length of the canal, extending from the Mediterranean to near the Bitter Lakes, passes mostly through fine sand more or less muddy, some portions passing through clay and mud of varying hardness and consistency, and some through agglomerated sand; but no portion offers serious difficulty to the dredger when excavating from underneath. There are also some beds of calcareous and gypseous formation more or less hard, but not very thick, and not expected to cause any great difficulty to a dredger with the ordinary buckets. Near the Bitter Lakes the soil changes entirely and becomes clayey, and a gypseous clay with a few alternations of sand forms the remainder of the distance to be traversed by the canal to the Red Sea; but this material is not expected to offer any remarkable difficulties to working by a dredger suitably constructed.

The canal starts from a point at Port Said on the Mediterranean coast, Fig. 1, where the water deepens most rapidly, in order to reduce the length of the jetties that have to be constructed. The line of the canal passes through the successive lakes, cuts through the elevated table-lands of El Guisr or El Ferdane and Serapeum, and the high ground at Chalouf, and crosses the Suez plain to the Red Sea at Suez. The section of the canal was originally intended to be made with 26 feet depth of water and 72 feet width at the bottom of the excavation, with slopes of 1 in 2, giving a width of water-way of 176 feet at the surface; but this width has been increased to 328 feet for the portions of the canal passing through the low ground and lakes, as shown in Fig. 3, Plate 51; and the slopes below the water line have been left to take the natural slope of the soil. For the cuttings through the high ground at El Guisr, Serapeum, and Chalouf, the section of the canal is that shown in Fig. 4.

The first operation consisted in cutting a freshwater canal, in prolongation of the old Ouady Canal from the Nile, for the purpose of obtaining a supply of fresh water for the men employed on the works; this prolongation was carried to Ismailia, where the head-quarters of the works are established near the middle point of the maritime canal. The line of the maritime canal through Lakes Menzaleh and Ballah was then commenced by excavating two side trenches, the spoil forming a continuous embankment along each side of the canal across the ground lying below the sea level; and the embankment on the African side was made strong enough to resist the action of the waves in the lake, and to carry the freshwater conduit on the top. A communication by water was then effected from the Mediterranean to the Red Sea by means of the freshwater canal, a branch of which was constructed from Ismailia to Suez, as shown in Fig. 1; and the channel though shallow sufficed for supplying the works, as long as hand labour alone was used. When the fellahs previously employed were withdrawn by the Egyptian Government, mechanical means had to be resorted to for continuing the works, and steam dredgers were then adopted.

The Dredgers used on the first 10 miles of the canal from Port Said are constructed entirely of iron, with one bucket frame, the foot of which is ahead of the hull, so as to be able to open the channel in advance of the vessel. The buckets hold 14 cubic feet each, and the shoots depositing the spoil on the sides of the canal are successively lengthened; the slope of the shoots being about 1 in 10, the wet mud and sand readily pass down them. All the movements for raising and lowering the bucket frame, for traversing across the canal, and for going ahead, &c., are performed by a condensing steam engine of 35 horse power with two cylinders.

On the next portion of the canal, extending to El Ferdane, the surface of the ground is somewhat higher than in the first portion, whereby not merely is the size of the spoil banks increased, but also the height at which the spoil has to be deposited; moreover the clay which here constitutes a portion of the spoil prevents it from spreading so far on falling from the shoot, and thereby further increases the height of the spoil bank. The mode of executing the work therefore on this portion of the canal was as follows. Leaving the trench on the African side for the boats bringing up supplies from the sea at Port Said, the Asiatic trench, which as a rule was originally cut narrower and shallower than the other, was enlarged first. All the soil above the water level was taken out by hand labour, and carried beyond the distance at which the dredgers were to deliver, in order to allow as much slope as possible for the dredger shoots; but notwithstanding this precaution, the shoots had still to be lengthened and sloped more gently than before. The dredgers employed for excavating below the water level are worked by engines of 14 to 18 horse power, at high pressure without condensers, having driving belts and cog wheels driving the tumblers. The hulls, which are of iron, are 72 and 82 feet long with 23 feet beam. In order to add to their stability with their long shoots, a wooden lighter 39 feet long by 10 feet beam was firmly lashed alongside. The buckets of these dredgers are from 3½ to 5½ cubic feet in capacity, as shown in Figs. 7 and 8, Plate 54; and the delivery is at the rate of about 20 buckets per minute. The shoots are made of sheet iron; they are 4 feet wide, their cross section being a semi-ellipse with the long axis horizontal, and they are inclined from 1 in 12 to 1 in 16, their length being from 65 to 72 feet. Sixteen of these dredgers have been used to make 18 miles of new channel, 59 to 65 feet wide and from 6 to 10 feet deep.

That portion of the spoil from the main channel of the canal which is not deposited upon the banks by the dredger shoots is delivered into ballast-lighters fitted to go out to sea, which discharge the spoil in deep water in the Mediterranean. In Fig. 25, Plate 63, is shown a transverse section of one of these lighters, which are similar in general construction to those shown in Figs. 21 and 22, Plate 61, only of larger build. The English sea-going ballast-lighters hold 217 cubic yards, and have one screw driven by an engine of 50 horse power working with surface condensers; these are excellent boats, both in form and construction, and also from the simplicity of the whole arrangement. Others built in France carry 261 cubic yards, and work at high pressure without condensing. The speed in both cases is about 7 to 8 miles per hour.

In the course of working, it was remarked that by the passage of the vessels, and especially of the small steam tugs, the sides of the canal were worn down somewhat rapidly when dressed to a slope of 1 in 2, and it was therefore proposed that the slopes should be pitched; but before this could be accomplished, it was found that the action of the waves had formed a sort of gently shelving beach, on which their force was then spent without further injury to the slopes. This clearly showed that all that was necessary for the further protection of the slopes was to shift back the spoil banks

A A to such a distance, as shown in Fig. 3, that not only might the slopes of the channel of the canal be made flatter without causing the sides and spoil banks themselves to give way, but also that there might be formed along the water line a sufficiently wide ledge B B to serve as a gently shelving shore for the waves to break upon. For this reason the width of the canal at the surface of the water was increased to 328 feet, as in Fig. 3; and the inner crests of the spoil banks A A were made 394 feet apart, or 197 feet distance on each side from the centre line of the canal. This necessarily increased the quantity to be excavated, and means had to be devised for depositing on each bank 246 cubic yards of spoil per yard run; and a most successful solution of the difficulty was found in the adoption of extra long shoots. But it then became necessary to give the dredgers an unusual height and to make the shoots 230 feet long; and it was consequently impossible to retain the same arrangement of the parts as in the smaller dredgers. The new arrangement however presented the great advantage of doing away with cranes, ballast lighters, and especially wagons for removing the spoil, which, running over banks made of mud or wet clay broken up by the buckets, were constantly getting out of order. Moreover with the aid of a few torches the dredger could be worked by night as well as by day.

The dredgers with the extra long shoots are shown in Figs. 5 and 6, Plates 52 and 53, and are fitted with a single bucket-frame C like the others, the foot of which is ahead of the hull; the hulls are 108 feet long and 27 feet beam, and the upper tumbler D is 48 feet in height above the water. The shaft of the engine carries a drum working two centrifugal pumps, for supplying water to facilitate the discharge of the spoil through the shoots. The length of the shoot E from the centre of the dredger is 230 feet, and its section is a half ellipse 2½ feet deep and 5 feet wide; the width of the vertical well into which the buckets discharge the spoil being greater than that of the shoot, a tapering junction is made of as great a length as possible. The shoot is stiffened lengthwise by two lattice girders which rest on the bottom of an iron lighter F placed at about one-third of their length from the dredger; the uprights G supporting the shoot are not fixed to the bottom, but jointed to a large horizontal spindle placed lengthwise in the lighter, and passing along its centre of displacement. A horizontal hinge couples the shoot to the dredger, and allows of its inclination being altered; this joint is covered by a piece of leather protected by sheet iron, over which the spoil passes, the leather and iron being fixed to the dredger only. In order to allow of changing the inclination of the shoot the uprights G resting on the lighter are made telescopic. The shoot is lifted by two small hydraulic presses worked by hand; blocks of a suitable thickness are then put into the slides of the uprights G, and the whole is bolted together.

For the purpose of facilitating the transport of the shoots, the framework supporting the shoot is cut in two horizontally above the slides just mentioned, so that when the shoot is detached from the dredger it can be turned on a sort of platform and brought into a position lengthwise with the lighter, the outer end being put upon a boat for that purpose. As it is necessary that the dredger in traversing across the canal from side to side should carry its shoot and lighter with it, the lighter is connected to the dredger transversely by a pair of chains H H, Fig. 6, with horizontal struts at right angles to the two hulls to serve as distance pieces; and a second pair of chains JJ run from the stern and bow of the dredger to the bow and stern of the lighter, whereby they are securely stayed together longitudinally. A pair of iron frames K K fixed to the dredger, and resting on the lighter and attached to it, make the two hulls like one piece in their vertical movements.

Many of these dredgers with long shoots are now at work satisfactorily, and fully realise what was expected of them; and twenty more are being constructed. It was feared that the swinging or traversing movement of the dredgers across the canal from side to side might be attended with some difficulty on account of their mass, and from the wind acting with so great a leverage; but these fears are found to be without foundation, as the dredgers are shifted just as easily as those discharging into ballast lighters. The swinging movement of the dredger is performed by means of chains L L, Fig. 6, from the four corners of the dredger to anchors with very broad and strong flukes. These chains pass through hawse holes 3 to 5 feet below the water, leaving sufficient depth of water above them for the boats actually used on the canal to pass over the chains; the hawse holes are found to wear away very quickly.

Only one form of bucket is used, of elliptical section and very conical, as shown in Figs. 7 and 8, Plate 54; and as this empties very easily it has not been considered necessary to try any other forms. It should be borne in mind that, beyond a certain size, the buckets empty very well, even when they work in sticky clays; because the adhering surface of the spoil is simply proportional to the square of the dimensions, whereas the volume and consequently the weight of the spoil is proportional to the cube of the same dimensions. Thus the weight increases more quickly than the adherence, and consequently the latter is always overcome beyond a certain limit of dimensions.

With these dredgers 48 feet high it will be easy, with the exception of certain short portions where the ground is too high, to complete the cut across the Mediterranean lakes and the Suez plain, Fig. 2, which form the two ends of the canal, and also to excavate the approaches of the Bitter Lakes, the whole amounting to more than half the entire length of the canal. Before constructing the dredgers 48 feet high however, it was necessary to proceed cautiously in exceeding the dimensions of the first dredgers of only 26 to 30 feet height; and experience showed that it was necessary to devise some new method for getting rid of the spoil in the higher ground. The formation level of the canal is throughout at the same height, and consequently the cubic quantity of spoil increases very rapidly as the ground rises; and as the crest of the spoil bank deposited on this high ground must be at least so far below the extremity of the shoot that the largest lumps which the buckets bring up may easily be got rid of, the height of the shoot and consequently of the dredger increases much more rapidly than the depth to be excavated. This necessitates increasing the strength of all the framework, the length of the bucket frame, and the weight of the chain of buckets; but the pins and links of the bucket chains had already reached very considerable dimensions and weights in the original dredgers, which made them inconvenient to repair. The first trial was made with dredgers only 10 feet higher than the original ones, and their excellent working encouraged the making of others still 10 feet higher; but it was evidently impossible to go much beyond the last height of 48 feet.

In order therefore to excavate the short lengths of the canal where the ground is too high for even the long-shoot dredgers of 48 feet height, an attempt was made to work with cranes carried on the canal banks, having 33 feet radius of swing, which were to take up the boxes filled by the dredgers and brought alongside in floats. The arm of the crane not being long enough to discharge more than a small quantity on the spoil bank, the remainder was to be run off in trucks in the ordinary way. The first thing necessary was that the canal banks and slopes should be sufficiently solid to carry the cranes and rails and loaded wagons, when sloped at the inclination of 1 in 2, which was necessary for allowing the floats to come alongside. After some months' trial on the most favourable portions of the canal, it was found that the action of the water on the slopes, and their general want of solidity under the weight put upon them, rendered this plan defective. The object then was to find some arrangement of mechanism which, whilst it should be capable of movement longitudinally, should be steady laterally, and should discharge at least one-half of the spoil direct on to the bank, without the use of wagons or any further handling.

These considerations led to the construction of an Elevator, which is shown in Figs. 15 and 16, Plates 57 and 58, and consists principally of two lattice iron girders M M, placed at right angles to the canal and resting half way on the bank; these support a pair of rails N N inclined about 1 in 4½, the lower end being about 10 feet above the water, and the upper end about 46 feet. A truck P running on the bank parallel to the centre line of the canal, 6 feet above the water, supports the girders in the middle, and the lower half towards the water rests on a lighter Q, the centre of which is 26 feet from the lower end of the girders; the upper half towards the shore is completely overhanging. The girders are tied together by vertical struts, and are strutted between their lower plates. The gussets at the middle are joined above the rails in an arch, and at their lower ends widen out and rest on the truck P. The two girders are thus supported at two points 13 feet apart, which gives them sufficient stability transversely, but allows of vertical oscillation, so that the inclination can be suited to the level of the water. They are attached to the lighter Q by a cast-iron block fitted with two trunnions placed horizontally and at right angles to each other; to this piece are secured four uprights, in the shape of an inverted pyramid, which are rivetted two and two to the girders, thus forming a universal joint.

On the inclined rails N of the girders runs a trolly R with external wheels, which is shown enlarged in Figs. 17 to 19, Plates 59 and 60; the pair of wheels at the lower end are fixed upon their axle, while the other pair are loose; and the axle of the latter carries two pairs of drums S S and T T of different diameters cast in one piece. On the smaller drum S is coiled a chain, to which the boxes U filled by the dredger buckets are to be hooked; on the larger drum T is coiled in the contrary direction an iron cable, which passing over a pulley O at the top end of the elevator runs down to a winding drum I fixed to the supports of the girders on the lighter Q. The drum I is worked by a two cylinder engine; the boiler is in the lighter, which contains also the water tanks and coal bunkers; and as the engine itself is fixed to the girders M M, the steam pipe passes through the universal joint uniting the girders to the lighter. The elevator is worked in the following manner. Supposing the trolly R is at the lower end of the incline and consequently outside the lighter, a float W is brought underneath, carrying boxes U U filled with spoil by the dredger, one of which is hooked on to the chain, and the engine set to work. The first effect is that the cable uncoils itself from the larger drum T on the axle of the trolly, Figs. 17 and 18, thereby winding up on the smaller drum S the chain hooked to the box U, which is thus lifted until the stop V touches the drum S; and as the chain cannot then be wound up any further, the cable drags the trolly up to the top of the incline, where the spoil is tipped by a self-acting movement. For tipping the spoil a pair of rollers X X, Figs. 17 and 20, are placed at the back of the box U and on the lower side, which are caught between two pairs of guiding rails Y Y parallel to the incline of the elevator; and shortly before getting to the top of the incline these guides rise in a curvilinear line, as shown in Fig. 15, so as to tip the box into a nearly vertical position for emptying out the spoil. By reversing the engine the trolly is allowed to run down to the bottom of the incline, and the box is lowered back again into the float.

The boxes U hold 4 cubic yards each, and their shape is similar to that of tip wagons, as shown in Figs. 17, 18, and 20; the bottom is lined with thin sheet iron, and they are made somewhat narrower at the back than in front, as shown in Fig. 20. The flap door at the front end is hinged on the upper edge, Fig. 17, and kept shut by a catch on each side, which is released by a self-acting chain at the moment of tipping the box. The floats W carry seven boxes each; they are made of two long rectangular chambers of sheet iron, 57 feet long, 3½ feet wide, and 4 feet high; these are kept 10 feet apart by eight openwork partitions between which the boxes are put, and when fully loaded they are almost entirely sunk in the water. Each dredger will ultimately have two elevators, one on each bank, and will get out a section of 300 to 450 yards length. If the final depth of the canal has to be excavated in three or four stages, the dredger will go up and down the length so many times, but the elevators will go only once.

In the Suez plain there was some difficulty about conveying the dredgers to the place where they were to commence work upon the line of the maritime canal, and it was impracticable to put them together on the spot. They are therefore put together and tried at Port Said, whence they are brought by water to Ismailia, and so passed into the freshwater canal by the two locks situated there; and they are then conveyed along the freshwater canal to a point about 5 miles from Suez. At this point has been excavated a sort of basin opening into the freshwater canal, and beyond is a second basin serving as a lock chamber; a communication is made between the two basins, and the dredgers with 82 feet shoots are floated into the second. They are then set to work and scoop out the bottom 6 feet deep below the sea level, and the communication between the two basins being stopped and the water allowed to escape from the second basin, the dredgers descend to their final level. They then cut their way to the line of the maritime canal and turn north and south, cutting a side trench right and left, along which the dredgers with 230 feet shoots can follow and complete the work.

In order not to be exposed to the rise and fall of the tide, the cut will not be made into the Red Sea until the works are sufficiently advanced for admitting the water into the smaller of the two Bitter Lakes, which will be temporarily shut off from the larger one by a small embankment constructed upon the ridge that forms the division between the two lakes, Fig. 2. A weir will then be put up at the mouth of the cut at Suez, having its upper surface about at the level of mean water, and fitted with sluices, so as to be able to retain the water in the canal up to the required level. The fall of the tide would otherwise impede the working of the dredgers.

The modes of working already described are those employed for cutting the canal wherever the surface of the soil is less than 6 feet above the sea level, that is, over a section about 56 miles in length, and including about 50 million cubic yards of excavation. Of this work the different implements have the following shares respectively allotted to them: dredgers delivering into sea-going ballast lighters, 13 million cubic yards; dredgers with elevators, 6 million cubic yards; dredgers with long shoots, 31 million cubic yards.

The higher ground along the line of the canal comprises the elevated table-lands of El Guisr and Serapeum and the high ground at Chalouf, Fig. 2. For the excavation at El Guisr, a cut was originally opened by hand labour to a level somewhat below that of the sea, and this cut is now being completed to the full width in the ordinary way, with wagons loaded by hand and drawn by small contractors' locomotives; in some places excavators are used for loading the wagons. This portion of the canal will then be completed by dredgers coming up from Port Said, which will deliver their spoil into lighters with flap doors at the bottom, and these will empty in Lake Timsàh, Figs. 1 and 2.

The lighters with bottom doors are shown in Figs. 21, 22, and 26, Plates 61 and 63; they are 108 feet long with 23 feet beam, carrying 160 cubic yards of spoil, and drawing 5 feet of water. They are fitted with twin screws and a pair of cylinders placed end to end; the engines work at high pressure without a condenser, with a tubular boiler at 120 lbs. pressure, using only fresh water. Whether loaded or light they make good a speed of 3 to 3½ miles an hour, and although made specially for lake work they can put to sea. Their construction is simple and economical; and it is found that high pressure engines are preferable to those of a medium pressure, as being simpler, lighter, and easier to keep in working order, and consequently more to be relied on for continuous work.

For the Serapeum cutting, Figs. 1 and 2, there is no means of bringing the dredgers and lighters in at the northern end direct from the Mediterranean, as at El Guisr; and they are therefore got upon the line of work by a similar plan to that already described in the case of the Suez plain, by cutting a channel from the freshwater canal to the line of the maritime canal. As the level of the freshwater canal is 20 feet above the sea level, it is not possible in this case for the ballast lighters to empty into Lake Timsah until the cutting has been excavated down to 6 feet below the sea level; and for depositing the spoil it was therefore decided to take advantage of three natural hollows which were found to extend transversely right and left of the line of the maritime canal, being formed by the undulations of the ground. By embanking these hollows at suitable points, and then filling them with water from the freshwater canal, shallow lakes are formed, of sufficient capacity to receive from the ballast lighters all the spoil excavated by the dredgers down to a depth of 26 feet below the freshwater canal or 6 feet below the sea level. When the bottom of the cutting has been lowered to this depth, the communication with the freshwater canal will be shut off, and the water allowed to run out into Lake Timsah; the dredgers will then begin again and work out the canal bed to its final level, the ballast lighters discharging in Lake Timsah.

For emptying the spoil in the shallow water of the temporary freshwater lakes, it became necessary to seek some new arrangement by which the ballast lighters could discharge in a very shallow depth; and the lighters constructed with flap doors at the sides are found fully to answer this purpose. These lighters are shown in Figs. 23, 24, and 27, Plates 62 and 63, and are 106 feet long. The well AA is 65 feet long, and is divided into two portions by a longitudinal air chamber B, Fig. 27, of a triangular section; the bottom of the boat, which is flat, forms the longest side of the triangle, and the vertex of the triangle is about level with the gunwales. The well A A is also divided across by five partitions into twelve compartments; the sides of the lighter are inclined slightly outward towards the top, and the flap doors of the compartments are hinged at the top; these doors are 4 feet high. The winches working the doors are inside the air chamber B, which is entered from both ends of the boat. The engines and boilers, which are the same as those on the other lighters with flap doors at the bottom, are in a compartment at the stern. These lighters carry from 100 to 120 cubic yards, and draw 4 feet of water.

The high ground at Chalouf, Fig. 2, will be cut through dry, and the stuff removed with barrows and wagons; these latter are entirely of iron, and hold 2½ cubic yards each. This portion, when excavated sufficiently low to admit the water from the Red Sea, will be completed with dredgers in the same way as the other portions, the spoil being discharged in the smaller of the two Bitter Lakes by ballast lighters with bottom doors. The sand on the previous portion of the canal was found to be completely impermeable to water when a certain depth was wetted; but the same is not the case here, as in the Suez plain the soil is clayey, mixed with some beds and pockets of sand. It has therefore been necessary to put up centrifugal pumps to keep the water under in the cutting, as the leakage is considerable from the freshwater canal, which is here at only a very short distance from the maritime canal. This water is run back into the smaller of the two Bitter Lakes.

To keep the numerous dredgers and engines in working order there are large shops at Port Said, and ten small shops on the different sections. In reference to the repairs, it may be mentioned that, in the first dredgers used at Port Said, the pins of the bucket chain were made some of iron, others of soft steel; but when working in the sand a pin of 2 inches thickness was found to be completely worn away after 16,000 to 20,000 cubic yards had been got out, and three or four days' stoppage was required to put in a new pin. The wages alone for the dredgers however amount to about £4 per day, with another £4 to £6 for the bargemen of the ballast boats, making a loss of about £8 to £10 per day, when they were stopped; and 4000 cubic yards would have been excavated during the three days. Pins $2\frac{3}{4}$ inches diameter with triangular heads were then made of the hardest possible steel; the head is fixed in the double link, as shown in Figs. 7 to 11, Plate 54, so that the single link takes all the wear, the eye being bushed with the hardest steel. After a certain time the pins are turned round one-third, and 48,000 cubic yards can now be excavated without turning the pin.

The upper tumblers of the dredgers, shown in Figs. 12 to 14, Plates 55 and 56, are made of cast iron, the arrises being steel; and sometimes these had to be replaced twice a month, which was a work of three or four days each time. These angle pieces, which had to be drilled and fastened on, have now been replaced therefore by a simple square steel bar A A at each of the four corners, passed through the flanges B B of the tumbler, and secured by a key C. Each of the four wearing faces of the tumbler is also protected by a steel plate D D, let in with a dovetail and secured by screws.

The following observations have been made as to the manner in which the different sorts of spoil pass down the shoots of the dredgers. The fine sands, which are the only sands met with, pass easily down a shoot inclined 1 in 20 or 25, if mixed with a quantity of water equal to about half their own bulk. When the shoot has a less inclination than 1 in 25, the water separates from the sand, which is thus deposited all along the shoot in layers of continually increasing thickness; the addition of a larger quantity of water does not seem to have any effect, and it is necessary to stir it up with a shovel. When the sand contains any shells, they are deposited in the shoot even with an inclination of 1 in 20, notwithstanding their lightness; and create round them deposits of sand, which continually increase, and have to be got rid of with shovels, or better still by increasing the inclination of the shoot. In this case again an increased quantity of water is not so efficacious as increasing the inclination of the shoot. Different degrees of fineness and muddiness in the sand, and different sections more or less flattened of the shoots, require different inclinations of shoot.

The top of the spoil bank has the same width as the extent of side motion of the dredger. The inner slope is more or less steep according to the means used to support it; the outer slope, if the top of the bank is high and the spoil has but little height to fall from the end of the shoot, varies from 1 in 16 to 1 in 25. The more muddy the sand is the gentler is the slope. When the top of the bank is low, and consequently the spoil falls from a greater height, the outer slope is gentler still. The sand when got out occupies only 2 or 3 per cent. more cubic space than in the solid.

Mud behaves very much like sand, if it is sufficiently soft to mix with water; and it will then pass down a shoot set with scarcely any perceptible inclination. The very softest mud, such as that got out of the old channels previously cut through the clay ground, does not require the addition of any water in the shoot. With clay it is quite different; the addition of water washes away only a very small quantity of the material, and hardly breaks up the lumps at all. If each lump of clay were to slide perfectly straight down the shoot, all would work well; most commonly however a lump winds about and soon stops, and the contents of the next bucket then drive it on 5 or 10 feet, and the whole increases the block. Others come after and increase the stoppage, till the mass gets 12 or 16 inches in thickness and reaches to the top end of the shoot, when the contents of the succeeding buckets seem to break it up, and the mass descends quietly and regularly in pieces of about 3 to 6 feet length. The shoots for clay are inclined from 1 in 12 to 1 in 16. With an inclination of 1 in 20 the lower end gets choked, which tilts that end of the shoot down and empties it, the work being thus carried on intermittently; with an inclination of 1 in 12 to 14 the work is more regular. When the clay is mixed with sand, the surface acts like a rasp, because the water washing away the clay makes the grains of sand more prominent and cutting, and thus seems to be rather detrimental. This is also the case when the buckets bring up hard clay and mud; the mud lubricates the clay and makes it run down more easily, whereas the water only washes the mud away.

In short, experience has shown that whilst a considerable supply of water must be added to sand, it is not so for mud or clay, to which only just enough water must be added for moistening the mass. Jets of water have not given good results; they merely wash down the points against which they are directed, and do not break up the lumps. The simplest and most convenient plan has been to put up a foot-way along the side of the shoot, and keep three or four men at work with scrapers to prevent its choking. In the long-shoot dredgers, with shoots of 230 feet length, an endless travelling chain is employed, as shown in Fig. 5, driven by the engine and furnished with a series of scrapers to carry the clay down the shoot. Generally the greatest difficulty with all kinds of spoil is in passing the first 40 or 50 feet length of the shoot; when once the material has passed this with any given inclination, it continues moving on down the same inclination without further difficulty.

The **President** mentioned that M. Borel had just returned direct from Egypt, and was therefore able to give the latest information about the progress of the works for the canal.

M. **Borel** said that he had just been spending three months on the Suez Canal works, and had left there his partner M. Lavalley, by whom the whole of the mechanical appliances for the construction of the canal had been specially designed for the purpose. The works of the canal were contracted for as long as 2½ years ago, but two years were occupied in designing mechanical means for excavating the canal and in constructing the machines and conveying them to Egypt and getting them to work; and he was happy to be able to state that the whole of the machinery on the canal had now been at work for more than six months with complete success in all respects. The greatest difficulty had been to convey the various machines to the places where they had to work, because it was necessary to have a channel of at least 50 to 65 feet width at the water line and 6 feet depth of water. The Mediterranean waters already extended inland in the first instance through Lake Menzaleh and Lake Ballah, and by means of an excavation made by hand labour had now been admitted into Lake Timsah; this lake, which was previously dry, extended to a distance of 50 miles from the Mediterranean. A channel of the required depth and width was then dredged, and the machines and materials were thus brought up as far as Ismailia, the head quarters of the works and about half way to Suez. They were here raised by means of two sluices to the level of the freshwater canal, which extended all the rest of the way to Suez; and from this canal three junctions were made with the line of the maritime canal, one at Serapeum, another at Chalouf, and the third in the middle of the plain between Chalouf and Suez. There were now 40 dredgers at work upon the canal, and the ultimate number would be 60, each excavating from 30,000 to 40,000 cubic yards per month.

The situation of Port Said had been chosen for the northern extremity of the canal, on account of the water deepening there more rapidly than at other parts of the coast, which was very flat; even at Port Said the depth necessary for the passage of the largest ships was only reached at a distance of about 2·2 miles from the shore. For forming a harbour for ships at the mouth of the canal, two jetties were being constructed at an inclination to each other, of which the western was intended to be 2 miles long, and the eastern jetty 1·6 mile. There was no stone to be found in the neighbourhood, but abundance of sand, which was mixed with lime brought from France; and for the construction of the jetties cubical blocks were made of this mortar or cement, each of 20 tons weight, which were carried out to sea in boats and sunk at the required spot. The west jetty, which was most exposed to the wind, was at present 1·4 mile long, and the other was 0·6 mile long; the works were going on very regularly, the number of blocks put in place being from 600 to 700 per month, representing about 9000 cubic yards. The total cubic content of the two jetties would be 333,000 cubic yards, of which more than one half was already completed; and at the present rate of progress, 9000 cubic yards per month, it was expected that the jetties would be completed within eighteen months' time. All along the inner side of the west jetty a channel had already been dredged to a width of 330 feet and 18 to 20 feet depth; and at the inner end of the port an area of 50,000 square yards had been dredged to the same depth, forming a harbour which received all the vessels that brought materials and coal to supply the works.

Leaving Port Said and proceeding southwards to El Ferdane through Lake Menzaleh and Lake Ballah, this length of the canal would be completed by the dredgers with long shoots, of which six or seven had already been at work for the last two or three months, and fourteen more were in course of construction, and were expected to be ready for work before the end of the present year. The dredgers at present at work were the original ones with which the first trials of dredging had been made on this portion of the canal, the spoil being then carried out to sea by the ballast lighters; and the long shoots were afterwards added for depositing the spoil on either bank in the parts of the canal distant from the sea. These dredgers had given very satisfactory results, and the last report just received from the canal stated that one of them had excavated no less than 58,000 cubic yards in the single month from 15 April to 15 May, the whole of the spoil being deposited upon the banks in its final position, so as not to require any further shifting. The natural slope taken by the spoil when deposited on the banks was very regular, and the spoil itself was extremely soft, so that it spread over a large surface; and the height of the spoil banks was therefore not so great as it had been feared beforehand would be requisite. At the same time if circumstances should ever occur requiring the canal to be widened, it would be easy to do this to a considerable extent without again moving the present deposits of spoil, because in this first length of 37 miles the crests of the spoil banks were nearly 400 feet apart, the material being deposited in that position by the dredgers themselves by means of the long shoots. In several portions of this part of the canal the dredgers were supplied with elevators for depositing the spoil on the banks where the ground was too high for the dredgers with long shoots. Eight of these elevators were at present in use, and they were found to work very steadily, notwithstanding the great length of the overhanging end. The number of boxes discharged by one elevator was from 15 to 20 per hour, making from 600 to 800 cubic yards of spoil raised and deposited by each elevator in every twelve hours.

At El Guisr the first great cutting was met with, which was being excavated down to the water level like an ordinary cutting by manual labour, the spoil being carried away in wagons by locomotive engines. Two thirds of this work had already been done, or about 7 million cubic yards, leaving about 3 million cubic yards remaining to be done, which would be completed down to the water level in less than one year; and the channel of the canal itself would then be excavated below the water line by the dredgers. There was already a water channel extending along the whole of this length into Lake Timsah, the width of the channel being 50 to 65 feet and the depth of water 5 or 6 feet, so that it was large enough to allow the passage of the dredgers and ballast lighters. The spoil from the dredgers would be discharged by the lighters in Lake Timsah, which although not very extensive in area was deep enough to receive the whole amount of spoil that had to be excavated in this length of the canal. The total capacity of the lake was about 130 million cubic yards, and the spoil would be deposited at a distance from the line of the canal, excepting where a short length of embankment had to be made in the lake; and along the whole length of the canal through the lake, dredging would be required to complete the channel of the canal to the proper depth.

The next length of the canal was that extending from Lake Timsah to the Bitter Lakes through the table-land of Serapeum.

On this portion of the work hand labour was at first employed; but when the fellahs were withdrawn by the Egyptian Government, it became necessary to employ mechanical means by having recourse to the dredgers, and these had been found both more economical and more reliable. As the surface of the ground however was at an average level of about 23 feet above the sea, some plan had to be devised for transporting the dredgers and the ballast lighters, and enabling them to be got to work at different points along the line of the maritime canal; and this had now been successfully accomplished in the following manner, by taking advantage of the freshwater canal, which had previously been extended from Ismailia to Suez. On examining the intended course of the maritime canal through the table-land of Serapeum, it was found that there were several undulations in the surface of the ground, running transversely to the line of the canal, which by the construction of several small embankments and by introducing the water from the freshwater canal were converted into artificial lakes, with a depth ranging to 7 or 10 feet below the water level of the freshwater canal. This water level was 20 feet above the sea level, or 3 feet below the surface of the ground along the course of the freshwater canal; and small branches of 65 feet width and 7 feet depth being then excavated by hand labour from the freshwater canal to each of the artificial lakes, these were thus filled with water to a level of 20 feet above the sea. The dredgers and ballast lighters were then raised from the sea level into the freshwater canal by the sluices at Ismailia, and brought along into each of these artificial lakes, where the dredgers were set to work excavating the course of the maritime canal which communicated with the lakes. The spoil was deposited in the lakes by the lighters, and it was for this portion of the work that the lighters with side doors had been constructed, so as to allow of discharging the spoil in the very shallow water of these artificial lakes. The capacity of the artificial lakes was sufficient for depositing in them the whole of the spoil excavated from this length of the maritime canal down to 7 feet below the sea level. As the dredgers excavated to a depth of 27 feet below the surface of the water, they would thus be enabled to complete the whole of the

Serapeum portion of the canal to a depth of 7 feet below the sea level; and when this had been done, the communication with the sea water would be made at the northern end, while that with the freshwater canal would be closed; the dredgers and lighters would then remain still afloat in 7 feet depth of water, and would be ready to proceed at once with the excavation of the channel for the canal to the final depth, the spoil being then carried to Lake Timsah. By this plan of operations the entire excavation of the canal through the Serapeum table-land was now being accomplished by means of dredgers and lighters brought up from the Mediterranean, and transported by water the whole distance to the very spot where they were required to be put to work.

The Bitter Lakes, through which the line of the canal next passed, were already sufficiently below the sea level to require no further deepening, except at the two ends and in the part that had formed the southernmost and smaller of the two lakes. In this part and in the cutting of Chalouf it had been found more advantageous to excavate by hand labour than by mechanical means. When the fellahs were taken away by the Government, it was thought at first that there would be a very small number of workmen to be had, and that it would be necessary to do the entire work by means of machines; but this was found not to be the case, and there were now about 10,000 men at work on the whole line of the canal, principally from Egypt, Greece, and Syria; it had therefore not been necessary to go to the trouble and expense of constructing special machines for excavating in the dry ground at Chalouf. Another consideration in favour of preferring hand labour was that a quantity of rock had been met with at this place, which was too hard to be cut through by dredger buckets in a sufficiently short time. The cutting was now considerably advanced, and there were at the present time fifteen or sixteen inclined planes, up which the loaded wagons were drawn by drums at the top worked by portable engines, and the spoil was deposited on each side of the cutting.

From Chalouf to Suez the canal was being excavated by the dredgers with long shoots and others with elevators. On account of the tides in the Red Sea, the communication of the canal with the sea at Suez was not intended to be opened at present, as the variation in the level of the water would interfere with the working of the dredgers; this last length of the canal was therefore filled with water from the freshwater canal, through channels excavated by manual labour, along which also the dredgers and elevators were brought from the Mediterranean. This arrangement had the advantage of floating the dredgers 6 feet above the sea level, thereby enabling the dredgers with long shoots to be employed over a greater extent of work than would otherwise have been the case, while at the same time fewer elevators were required.

In selecting the point for the entrance of the canal into the Red Sea at Suez, some difficulty was experienced at first, because the borings showed the presence of a large quantity of rock, a sort of sandstone. By subsequent borings however a line more to the east was at length found completely free from rock, so that the ground could be excavated by the dredgers. At the port of Suez the natural ground was very solid, and was therefore not liable to be washed away. For this mouth of the canal no great works were required, and there were no jetties to construct, except a short jetty to protect the harbour from the south winds; a large embankment was to be made on one side of the channel for the docks and various buildings required by the future traffic of the canal. The width of the channel was increased at the mouth from 330 to 1000 feet, so as to afford a large entrance for ships.

The various machines employed upon the entire line of the works had now all been in operation for a sufficient length of time to allow of a correct estimate being formed as to their capabilities, which had proved even greater than had been hoped beforehand; and he had therefore no doubt that, from the present rate of progress, the whole canal would be completed from end to end by the close of 1869, provided that no financial difficulties interfered to delay the work. During the past few months the works had been visited by a great number of persons returning from India, among whom were many military engineers, who had expressed great satisfaction at the very successful manner in which the operations were being performed by the various appliances now in use, and at the practical solution which had thus been arrived at of the many difficulties encountered in this most important undertaking.

Mr. C. **Cochrane** enquired whether there had been any difficulty in excavating the channel of the canal through Lake Menzaleh, from the mud flowing in again on both sides as fast as it was excavated by the dredgers, in consequence of the ground being entirely submerged below the water level; and he enquired whether it had been necessary to construct barriers below water along the course of the canal, before the excavation of the channel was commenced by the dredgers. He asked also whether there was mud in the Bitter Lakes, or whether they were quite dry to the very bottom.

M. **Borel** replied that there was no mud in the Bitter Lakes, but the bottom of the lakes was a bed of salt, overlying a stratum of gypseous clay; the bottom was perfectly dry, although the whole length of the lakes was below the sea level. In Lake Menzaleh, through which the canal passed for a length of nearly 30 miles, a large quantity of mud had been deposited from the waters of the Nile flowing through the lake, forming a layer of light and soft mud of about 2 feet thickness along the line of the canal; and under this was found the original bottom of sand and mud, of variable hardness. In excavating the first shallow channel through the lake, to form the means of transport from Port Said to Ismailia, this mud had to be removed by hand labour, the men working breast-high in the water; and when the spoil was deposited too near the channel, it was found to spread considerably and force back the soft mud into the excavation, so that the spoil banks had to be removed further from the line of the canal. At the present time however the dredgers were working in the old ground underneath the mud, and several of them had already reached a depth of 16 to 20 feet. The natural slope of this ground was found to be generally 1 in 2½ or 1 in 3 ; but in some places it was as much as 1 in 1, and occasionally the earth was so hard and firm that it would stand with the sides quite vertical. A certain amount of variation had therefore been allowed in the slope of the canal banks, according to the variable hardness of the earth at different places. No difficulty had been experienced in maintaining the canal slopes afterwards, as they were found to stand perfectly sound when originally executed at the proper inclination.

Capt. F. **Beaumont** enquired whether any special means had been proposed for preventing the canal from becoming choked up by the sand deposited in it from sand storms, or whether it was considered that ordinary dredging would be sufficient for the purpose of keeping the channel open.

M. **Borel** replied that the only portions of the canal where there was loose sand which could be blown about by the wind were the cuttings at El Guisr and Serapeum. At this part there were hills of sand, some of them about one mile in length, making up altogether probably about ten miles length along the course of the canal. From Serapeum to Suez there were no sand hills, the ground being composed of clay mixed with gypsum. A certain quantity of sand was put in motion by the strong winds; but the sand storms were very rare, and the actual quantity of sand in them was not great, as a cloud of sand which would be formidable enough to travellers would not deposit a sufficient quantity of sand in the canal to produce any inconvenience to the traffic. The length of canal exposed to the action of sand storms was only about ten miles, and the whole amount of excavation along that length was about 20 million cubic yards. The quantity of sand moved by the winds on a length of five miles in the northern portion of the El Guisr cutting was found to be only about 40,000 cubic yards in the space of two years; and upon a measured length of one mile in the Serapeum cutting, it had been found that the total deposit of sand in the canal during one year amounted to not more than 32,000 cubic yards. When it was considered that each dredger would excavate 400,000 cubic yards in a year, it was evident that the two or three dredgers intended to be kept permanently at work on the canal would be amply sufficient to clear out all the sand which might happen to be drifted into it.

Mr. R. **Price Williams** mentioned that a plan had been successfully employed by Mr. Hawkshaw in Holland for removing the spoil from excavations in very light ground, by mixing with the spoil a sufficient quantity of water to render the whole so fluid that it could be forced through a flexible tube over the embankment; and the tube itself was carried upon a timber float, so as to follow the variations in the level of the water. This arrangement had the advantage of obviating the necessity for long shoots to the dredgers, and of saving power in discharging the spoil; and he suggested that the same plan might perhaps be found applicable on the Suez canal, in the dredging of the embanked portions.

Mr. R. Mallet enquired whether the maritime canal opened a communication between Lake Menzaleh and the Mediterranean at Port Said, so as to allow the Nile water entering that lake to flow out thence into the sea, and thus to deposit its mud in the harbour.

M. Borel replied that the canal was being embanked on both sides along its entire length through Lake Menzaleh, but the embankments were not yet sufficiently advanced to keep out the water of the lake altogether, and there was at present therefore an outlet for the Nile water into the sea through the harbour of Port Said. As fast however as the deepening and widening of the channel was advanced by the dredgers, the embankments were enlarged and consolidated by the deposit of the spoil; and when they were completed to the final height, the water in the lake would be entirely cut off from the harbour, so that there would be no possibility of any deposit from the Nile in the harbour. The temporary section of channel, 65 feet wide by 7 feet deep, had for some time been completed all the way from Port Said to Lake Timsah, and by this means together with the freshwater canal the materials were now conveyed by water from the Mediterranean to Suez; there was thus already a line of water communication entirely across the Isthmus, in one half of which the channel only required deepening and widening to form the permanent maritime canal.

Mr. R. Mallet enquired what observations had been made in reference to the sand drifting with the marine currents along the Mediterranean coast eastward or westward past Port Said, and whether it was found to be brought in and deposited in the harbour in any states of the wind.

M. Borel replied that the prevailing wind at Port Said was from the west, and all along that part of the Mediterranean coast there was a current from west to east, which continually shifted the sand forming the shore. But at the depth of 26 to 30 feet, which was necessary to float ships, the bottom was only mud, and no sand was deposited there. Since the commencement of the western jetty, the sand had gradually accumulated on the shore, and the shore had advanced along the jetty about 200 yards. But as the dip of the shore was at the same time increased by its advance, he did not know whether the same action would be continued much further along the jetty, or whether it would ever reach the end of the jetty. Even if this should be the case however, the process of silting up by deposit of sand was so slow that a single dredger would always be able to keep the channel clear to the full depth.

Mr. R. **Mallet** enquired whether the actual difference of level between the Mediterranean and the Red Sea had been accurately determined by the levellings for the line of the canal, and what had been found to be the amount.

M. **Borel** replied that the level of the Mediterrancan at Port Said was found to be about 12 or 15 inches above the mean level of the Red Sea at Suez, and the rise and fall of the tide at Suez was ordinarily only about 3 feet above and below the mean level; the highest tide under the equinoctial wind had risen to 4½ feet above the mean level or about 3 feet above the Mediterranean.

The **President** moved a vote of thanks to M. Borel, which was passed, for his valuable paper, and for the very interesting description which he had given of the present state of the works along the entire course of the canal from Port Said to Suez.

The following paper was then read:—

DESCRIPTION OF A 30-TON HORIZONTAL DUPLEX HAMMER.

By Mr. JOHN RAMSBOTTOM, of Crewe.

The Hammer described in this paper arose out of the writer's belief that it was necessary to provide some means more powerful than any before used in England, and at the same time convenient and handy, for the forging of steel in large masses. His attention was first drawn to this question when he was engaged in laying out the Bessemer Steel Works of the London and North Western Railway at Crewe. The first intention was to put down a 30-ton vertical hammer of the ordinary kind;. but as this would have required an anvil of 300 tons, the practical difficulty and cost of dealing with so large a mass suggested to the writer that the principle of *action and reaction* might afford a solution of the problem. Hence-arose the conception of two hammers acting in opposite directions; and as a matter of convenience it seemed better to lay them on their side and cause them to operate horizontally upon a bloom placed between them. As this idea grew into form it appeared to present advantages both in economy and convenience sufficiently important to warrant the construction of an experimental hammer of 10 tons. This when brought into operation proved to possess the advantages expected; and in consequence the writer designed and laid down the 30-ton hammer which forms the subject of the present paper.

General Description.—The Duplex Hammer is shown in Figs. 1 to 4, Plates 64 to 66, and consists of two similar cast-iron blocks A A, forming the hammer tups, which are placed with their heads towards each other; each is mounted on eight wheels, and connected at the hinder end by a piston-rod B to a piston working in a cylinder C of 38 inches diameter and 42 inches stroke. Each block with its piston and rod weighs 30 tons. The steam pipe D occupies a position midway between the two cylinders C C, and two branches E E are carried from it, one to each cylinder, so that each receives an equal supply of steam. The mean pressure throughout the stroke is 30 tons on each piston; and the effect is consequently the same as that which would be produced by the action of gravity upon the hammer tups through a fall equal in length to the stroke. The wheels F F run on steel-headed rails, bolted down upon the cast-iron girders G G, on the hinder ends of which the cylinders rest and are bolted down by their flanges.

Hammer Tups.—For convenience the hammer tups are each cast in two pieces, jointed transversely at the centre, and held together by two wrought-iron hoops H H shrunk on bosses cast on each side of the half-tups for this purpose. Two wrought-iron dowel pins I I, Fig. 1, 4 inches diameter and 13 inches long, driven half their length into each half tup in a longitudinal direction, prevent any independent side play.

Wheels.—The wheels F F are of cast iron, chilled on the circumference and flanged; they are 18 inches diameter, and the centre hole is 6½ inches diameter, reduced by a brass bush to 5¼ inches diameter, as shown in Fig. 3; they run loosely on Bessemer steel axles, which pass right through the bodies of the tups. These axles are 5½ inches square in the centre, as shown in Fig. 1, and are turned at the ends to fit the wheels, the journals being thus 5¼ inches diameter and 15 inches long. The holes in the body of the tups are 7½ inches square, and the axles are secured in them by wood packing J, Fig. 3, and iron wedges driven in at each end of the holes; this is considered better than bored holes and an absolutely rigid fit.

Piston Rods.—The piston-rods B B are of Bessemer steel, 8 inches diameter. They each carry at the forward end a head K, Fig. 1, 16 inches diameter and 8 inches long, forged solid upon the rod, as shown to a larger scale in Fig. 5, Plate 67; this head enters a hole in the hinder end of the tup A, 16½ inches diameter and 18½ inches deep. A wrought-iron washer-plate L, 2 inches thick, is passed along the piston-rod from the other end, and is fastened by studs to the hinder end of the tup, the diameter of the stud circle being 21¾ inches. A packing of india-rubber 1-8th inch thick and wire-gauze in alternate layers is interposed between the head of the piston-rod and the tup; this packing is 8 inches thick in front of the head, and 3 inches thick behind, between the head K and the washer-plate L. One of Ramsbottom's pistons of cast steel is fastened to the other end of the piston-rod in the ordinary manner, as shown in Figs. 1 and 2.

Valve Chests.—The valve chests M M, Figs. 1, 2, and 4, are cylindrical, and are shown to a larger scale in Figs. 6 and 7, Plate 68; they are both on the same side of the hammer, so that the cylinders are right and left handed. The valves N N are the ordinary cylindrical valves, turned to fit accurately in the chests. The ports consist of holes 1 inch wide by 1¼ inch long, placed in a circle all round the valve chest, as shown to a larger scale in Fig. 8; thus an area of 36 square inches is obtained with a length of valve stroke of only 3½ inches. The steam pipe E is brought vertically upwards under the valve chest, which it joins in the centre of the bottom side. One of the lengths of this pipe has a horizontal branch O, containing a counterpoising lever P; a link Q fastened to the short arm of the lever passes vertically up the centre of the pipe E, and is provided with a rounded head 5 inches broad and 1 inch long, which fits into a recess made for it in the underside of the valve N: on the long arm of the lever P a weight R is so fixed that the weight of the valve is exactly balanced, and friction is thereby avoided. The two valves are each connected by a series of links to a shaft S, Figs. 1, 2, and 3, passing below the ground level; and a handle T on this shaft is brought up above the ground in such a position that the attendant working the valves is in full view of the hammer faces.

Connecting Screw.—In order to ensure the two hammer tups A A moving simultaneously, and striking the bloom exactly at the same instant, a steel screw-shaft U, Figs. 1, 2, and 3, is carried underneath the tups in the centre line of the hammer, and is provided with a right-and-left-handed thread, on which work two brass nuts V, one fixed to each tup, the screw-shaft being free to turn in fixed bearings carried by the foundation girders G G. If the screw-shaft were turned round independently, it would draw the two tups together at an equal speed, making them meet exactly in the centre, or it would cause them to separate at an equal speed; consequently when the two tups are moved each by its own piston, any difference in the rate of their motion is prevented by their constant connection through the screw-shaft. This shaft is 4½ inches diameter in the solid and 6 inches diameter outside the threads, as shown to a larger scale in Figs. 9 to 12, Plate 69; the pitch of the threads is 9 inches, and there are six threads to the pitch. The nuts V are each cast in four quarters, the planes of division being both vertical, one tranverse and the other longitudinal; the wear is taken up in both directions by wrought-iron wedges provided for this purpose, with adjusting set-screws X X; the total length of each nut is 24 inches. Each end of the screw-shaft U abuts on a brass step Y, Figs. 9, 12, and 13, which is held between two snugs on a cast-iron block fixed transversely between the girders G G. These steps are adjustable by means of wrought-iron tail-screws Z with lock nuts, as shown in Figs. 9 and 12. If one of the hammer tups had a tendency to over-run the other, it would cause end-play in the screw-shaft U, and the fault would be shown by the greater wear of the step Y at the further end; and consequently the fact that the two steps wear equally proves that there is no tendency to end-play in the shaft, and therefore that the motion of the one tup balances that of the other.

Girders and Foundation.—The two pairs of girders G G, Fig. 1, which carry the hammer tups and cylinders, rest at their hinder ends directly on the stone foundation, and at their forward ends upon another pair of girders P P, Figs. 1 and 3, supported on the stone foundation, one on each side of the centre line of the hammer; the foundation being lower at the centre than at the two ends, as shown in Fig. 1. The foundation consists merely of brickwork laid on the natural clay of the district, 2¾ feet thick at the centre and 5½ feet thick at the two ends, with 2¾ feet of stone on the top of all, as shown in Figs. 1, 3, and 4. The girders are held down upon the stone by long bolts passing through the stone and brickwork, Figs. 3 and 4.

Ingot Trucks and Rocking Table.—The ingots while being hammered are held between the two hammer faces in trucks designed for the purpose. These rest on a rocking table W, Figs. 1 and 2, to which a slight tilting movement can be given by the attendant, so as to keep the ingot always in the centre between the hammer faces, and ensure its being struck by both hammers simultaneously. The table is formed of a cast-iron plate W, 22 inches wide and about 17 feet long, cast with a half-round projection on the underside all along the centre, which rests in four half-round bearings R R, Figs. 14 and 15, each 8 inches long, placed in the centre line of the cast-iron plate W and transversely to the hammer. The plate W is connected by linkwork with a handle Q, Figs. 1 and 2, placed in convenient reach of the attendant, for tilting the table slightly as may be required. The upper side of the table is grooved to admit the wheel flanges of wagons of 18 inches gauge, as shown in Figs. 15 and 16.

Truck for Ordinary Ingots.—The truck employed for supporting the ordinary description of long narrow ingot is shown in position between the hammers in Figs. 1 and 2, and to a larger scale in Figs. 14, 15, and 16, Plates 70 and 71. It consists of a carriage of boiler plate A, Fig. 14, 12 feet long and 19½ inches wide, running on four cast-iron wheels. The ingot B is held between two centres C C, carried in two headstocks D and E, in a manner similar to that in which a shaft is held in a lathe. One of these headstocks D is bolted to the bed of the carriage A; the other E is free to slide upon it. The gradual extension in length of the ingot during the hammering is provided for in the following manner. A central screw-shaft F F runs from end to end of the carriage below the headstocks; to the underside of the moveable headstock E is attached a crossbar G, having an opening in the centre to admit the free passage of the screw F. A short distance behind this, between the side pieces of the crossbar G, a wrought-iron nut I is placed upon the screw, and is prevented from turning round by wings on each side, which project underneath the side pieces of the crossbar G. A helical spring J is wound round the screw-shaft between the nut I and the crossbar G, which are prevented from separating beyond a certain distance by two bolts passed through each. At the forward end of the carriage a crossbar H, Fig. 15, bolted to the frame, carries two small wooden break-blocks, which act against the face of a spur-wheel K keyed on the end of the screw-shaft F. The pressure of the spur-wheel against the break-blocks is regulated by a transverse laminated steel spring L, Fig. 16, fixed at the other end of the carriage; on this tail-spring the hinder end of the screw-shaft F abuts, a brass step being interposed between the end of the shaft and the steel plates.

When a blow is delivered, the consequent extension in length of the ingot B causes the moveable headstock E, and with it the crossbar G, to slide backwards along the bed and compress the helical spring J. The reaction of this spring against the nut I forces the screw-shaft F endways, deflecting the tail-spring L. The pressure of the break H at the forward end being thus reduced, the screw-shaft revolves, allowing the nut I to slip along it, until the reaction of the tail-spring L restores the pressure on the break-blocks and prevents all further motion. For enabling the attendant to adjust the moveable headstock E to any required length of ingot before the hammering, and for admitting of the easy removal of the ingot when finished, the spur-wheel K on the forward end of the screw-shaft F is made to engage with another spur-wheel to which handles M are affixed, Fig. 15; a set-screw at this end acting on the screw-shaft removes all pressure from the break, and the shaft is then easily turned round as required. This truck is moved backwards and forwards on the rocking table W by hydraulic power.

Tyre Truck.—Another truck has been constructed for holding the conical ingots used in the manufacture of solid weldless steel tyres. This is shown in Figs. 17 to 21, Plates 71 and 72. It consists of a carriage of boiler plate A, placed upon the rocking table W, and carrying two pairs of rollers N N and P P, on which the conical ingot B lies with its axis horizontal, Figs. 18 and 19. One pair of these rollers N N, carrying the large end of the ingot, are 11¼ inches diameter by 9 inches length and 3¼ inches tapered, and remain fixed in position. The other pair of rollers P P are 9 inches diameter and 1½ inch thick, and are carried in a wrought-iron frame Q, which slides vertically within wrought-iron guides, and is supported by a long wrought-iron wedge I. This wedge, which is 6 feet 10 inches long, is driven home at the commencement of the hammering, and is gradually drawn out so as to lower the supporting rollers P P by degrees, and accommodate their height to the increasing diameter of the centre of the ingot B during the hammering. The rate of withdrawing the wedge I is regulated by the attendant, who has thus complete facility for adjusting the ingot constantly to its true level between the two hammers with as great accuracy as if he were holding it by hand. The taper in the fixed rollers N N allows for the slight increase in diameter of the base of the ingot, which advances downwards towards the small ends of the rollers as the hammering proceeds. The ingot is continually turned round upon these rollers during the hammering by means of ordinary pinch bars. In the centre of the frame Q is a socket S, into which fits the stalk of a small mushroom turntable T, Fig. 17; the ingot is placed on this turntable with its axis vertical, for hammering all round the circumference, and it is easily turned round between each blow by means of an ordinary spanner. The truck A is kept in position on the rocking table W by projecting studs which fit into the grooves on the table.

Truck for Bars.—Another truck, shown in Figs. 22 to 24, Plate 73, is used for supporting ingots for bars. In this the bar B rests on six rollers carried in a boiler-plate frame A, which is placed on the rocking table W between the hammer faces, and kept in position by projections fitting into the grooves of the table; the rollers are placed one behind another along the length of the frame A. The two central rollers C C are 5 inches diameter and 14¾ inches long; the rest are 7 inches diameter and 14¾ inches long. The ingot B is shifted endways along the rollers by means of ordinary pinch bars.

Truck for Long Shafts.—In the forging of long shafts the work is supported on a pair of trucks A A, one at each end of the shaft B, as shown in Figs. 25 to 27, Plate 74. These trucks are exactly alike, each carrying two cast-iron rollers C C, Fig. 25, between which the shaft B lies. In order to retain the axis of the shaft always in the centre line of the hammer, whilst its diameter continually decreases, the supporting rollers C C, which are 6 inches diameter and 2 inches wide, are carried in a cast-iron frame D that can slide upon the body of the truck A up an incline of 1 in 4. A screw E fastened at the upper end to the body of the truck, and engaging with a nut in the sliding frame D, enables the attendant to adjust the height of the rollers and the shaft between them, as may be required from time to time. The two trucks are prevented from separating from each other by a wrought-iron link G. The whole runs on eight wheels, and is moved to and fro on the rocking table W by hydraulic power.

Peel Bar.—The ordinary method of lifting ingots out of the furnaces and carrying them to the hammer is to make use of a peel bar as a lever, on one end of which is the ingot, and the other end is either weighted or held down by a number of men, the fulcrum being supported by a chain from a crane or beam overhead. Instead of the chain, a curved wrought-iron link A is employed by the writer, as shown in Figs. 28 and 29, Plate 75; the peel bar B is wedged fast in the socket C in the link, and its weight is counterbalanced by the adjustable weights D at the outer end of the curved link A. By this means the point of support E of the whole is brought vertically above the ingot G, so that the carrier is always in equilibrium whether loaded or unloaded; and when the peel bar is run into a furnace and underneath an ingot, the point of support E is over the roof of the furnace and vertically above the ingot. By this arrangement one man at the end of the peel bar is enabled readily to handle an ingot of any weight, as he has merely to guide it in its progress to the hammer.

Character of Work.—To show the character of the work done by this duplex hammer it may be mentioned that, in drawing down a crank-axle ingot from its cast size of 20 inches × 24 inches and 3 feet 5 inches long to the form of a slab $11\frac{3}{4}$ inches × $21\frac{1}{2}$ inches and 5 feet 10 inches long, 312 blows are delivered. Of these blows 84 are light and are merely finishing blows, the preceding 228 being sufficient to do all the heavy part of the work, and these are delivered at the rate of 48 per minute with a stroke of rather more than 2 feet for each tup. The total time occupied is about 25 minutes. The slab when finished is slightly round at the ends, the length of the axis being a few inches greater than that of the surface, thus showing clearly that the blows penetrate quite to the centre of the ingot. The appearance of some defective crank-axle ingots which were broken when cold confirms this view, the metal being found to be of the same texture throughout—as continuous and solid in the centre as at the surface.

Chief Advantages.—Among the chief advantages which this form of hammer possesses are the following:—

It requires no anvil, the whole moving force of each hammer tup being balanced by the one opposed to it. Hence the cost of laying down and afterwards of occasionally lifting an anvil is avoided. A comparatively shallow foundation is required, a matter of great importance where drainage is difficult.

The action is equivalent to that of a vertical hammer with an anvil of infinite weight. Comparing it with a single 30-ton vertical hammer, it is evident that each block weighing of itself 30 tons has only to be moved through one half the space in order to produce the same effect; a greater number of blows can therefore be delivered in the same time. The blows being given simultaneously on opposite sides of the bloom, meet in its centre, and the resistance due to the inertia of the mass operated on is reduced by one half. The blows being in opposite directions counteract each other; hence no vibration is produced, and consequently no damage is done to the surrounding buildings and machinery.

The hammer is therefore an economical instrument both in first cost and cost of maintenance. In working it will be seen that the scale can fall away quite freely from the bloom, and also that there is great ease in the manipulation, and consequent accuracy in the forging of large masses: for instance the upsetting of a long crank-shaft can be performed with ease, an operation of great difficulty under the ordinary vertical hammer. It thus appears that the hammer will be specially convenient for the forging of guns and other long and heavy articles, more particularly since it can be made of larger dimensions at a comparatively small increase of cost. It may be conveniently worked in conjunction with a vertical hammer; by which means forgings that require two kinds of treatment may be easily dealt with. Also it can be used in buildings which from want of height could not contain a vertical hammer of the same effect.

The **President** remarked that he had seen the horizontal duplex hammer at work at Crewe, and it was certainly one of the most ingenious pieces of mechanism that he had ever seen, comprising a number of novel mechanical contrivances, every one of which was worked out in a most complete manner. The work turned out by the hammer was perfect, thoroughly sound and well finished in all parts; and having seen the working of the hammer on several occasions, after it had been in use for a considerable time, he understood that not the slightest trouble had been experienced in using it. Such a machine he thought must speedily come into general use, wherever forgings of considerable size had to be dealt with. He enquired how long the hammer described in the paper had now been at work.

Mr. **Ramsbottom** replied that the present 30 ton hammer described in the paper had been at work nearly five months; and the previous 10 ton experimental hammer had been working constantly for about three years. The object he had aimed at in designing the horizontal duplex hammer had been to get a very powerful hammer at comparatively little cost, and with as little vibration as possible to the buildings and works; at the same time it was necessary for the hammer to be so arranged as to be useful not only for the heaviest forgings, but also for ordinary work. In the working of steel forgings in particular, his own experience had led him to the conclusion that the ordinary modes of working were very faulty, in consequence of not putting work enough into the mass of metal operated upon; and he considered that up to the present time there had been no means at all proportioned to the work to be done. The result was that the skin of the metal was too much hammered and the centre too little, so that the external portions became unduly drawn out, which caused the centre parts to be torn asunder and thus rendered unsound. This was in consequence of the forging not being performed by hammers with sufficient moving mass; and he did not believe that the desired effect of blow could be attained by mere velocity, nor that the absence of a sufficient mass in the hammer itself could be compensated for by increasing the speed of the hammer. What was wanted was a blow somewhat approaching a squeeze, and this could not be obtained by velocity, but only by the adoption of a heavier mass.

The horizontal duplex arrangement of the hammer however, notwithstanding the greatly increased weight of the masses put in motion, admitted also of great rapidity of action, in consequence of the strokes of the two hammer-blocks being made simultaneously, so that what was in fact a 4 feet stroke was got by moving each hammer only 2 feet. In this way he had obtained as many as 48 blows per minute from the 30 ton hammer, a greater number than could be obtained from a 5 ton vertical hammer working alongside and supplied with steam from the same boiler. They were thus enabled to get through the work while it was hot, which in itself was a point of importance in respect to economy. Another advantage of the heavier hammer was that the original steel castings could be forged in larger masses, and worked down to the desired shape with greater economy and better effect than under a lighter hammer. Although the work to be done at Crewe was in general not of a heavy character, the heaviest forgings being those for locomotive crank-axles, yet he did not think the 30 ton hammer now employed was larger than was required for effectually performing the work.

Mr. C. **Cochrane** observed that in the truck for ordinary ingots (Plate 70) the work was carried upon a pair of centres like lathe centres, and there appeared a great possibility of its dropping out under the blows of the hammer. He enquired whether any such accident had occurred, and in what manner the original centre holes were made in the two ends of the ingot for fixing it on the centres, so as to be large enough for holding it securely.

Mr. **Ramsbottom** replied that it had only once happened that the work dropped out from between the centres supporting it; and the accident occurred in consequence of the breakage of the helical spring (J, Plate 70) by which the moveable headstock was kept in position. Very slight centre-holes were found sufficient, which were made with a centre punch in the usual way by a blow from an ordinary sledge hammer; and there was found to be very little tendency for the work to get out, when once fixed on the centres of the truck. The metal seemed during the hammering to spread lengthwise to a slight extent round the centres, thus making the centre holes deeper; and it was a curious circumstance, which he had not been able to account for, that the centre points themselves were found to become more pointed, instead of being made more blunt by the effect of the hammering as might have been expected; this was the case more particularly with the centre in the fixed headstock.

The various trucks supporting the different sorts of work during the hammering were at present he considered the least satisfactory part of the arrangement, and it was in these that further improvement was most desired. The simplest and most effective of the plans yet tried was the six-roller truck used in forging long bars (Plate 73); but this was of course not available for general roughing-down, for which a sort of centre carriage was required, more like those used for holding the ordinary ingots (Plate 70) or the tyre blooms (Plate 72). The general practice with the duplex hammers, even in forging long bars, was to finish the forging from end to end in a single heat, so as to prevent the waste of skinning the iron over with a coat of oxide by a second heating. In this way also a great deal of time and skilled labour was saved, as well as the fuel required for a second heat.

The President enquired whether the cylinders of the hammer were provided with steam jackets; and also whether there was found to be any difficulty from wear of the stuffing-boxes.

Mr. Ramsbottom replied that the cylinders were not steam-jacketted, but the condensed water was got rid of in the usual way by blow-off cocks. He had not experienced any trouble from wear of the stuffing-boxes, as the piston-rods were so thoroughly guided.

The President moved a vote of thanks to Mr. Ramsbottom for his paper, which was passed.

The **President** proposed a vote of thanks, which was passed, to General Morin and the authorities of the Conservatoire Impérial des Arts et Métiers, for their kindness in granting the use of the Lecture Theatre for the purpose of the meeting, and the facilities they had afforded in connection with the meeting; and also to the Honorary Local Secretary, Mr. Henry Chapman, for the very efficient and valuable assistance rendered by him in promoting the success of the meeting.

The Meeting then terminated; and in the evening the Members and their friends, with a number of guests invited for the occasion, dined together at the Trois Frères Provençaux, Palais-Royal, in celebration of the meeting of the Institution in Paris.

On Friday, 7th June, the Members visited the Observatory, upon the obliging invitation of the astronomer royal, M. Leverrier, who conducted them over the building and explained the construction and action of the principal instruments employed in the astronomical observations.

The Members then visited the Artesian Well Borings in progress of execution by M. Dru at Butte-aux-Cailles and at M. Say's Sugar Refinery, the description of which had been given in the paper read by M. Dru at the meeting on the previous day. At Butte-aux-Cailles a breakage of the boring rod had occurred shortly before the arrival of the Members, and they had thus an opportunity of witnessing the process adopted for recovering the broken portion left at the bottom of the bore-hole, by lowering a conical socket filled up on the underside with wax, to take an impression of the fractured end, preparatory to sending down a conical screwed socket, to screw upon the broken end for bringing it up. At the Sugar Refinery the boring was seen in progress, with the reaction tool liberated by the shock produced at the top of the stroke.

The Members were also shown the several processes of the sugar manufacture,—the boiling of the raw material, the separation of the liquid molasses and the drying of the brown sugar by centrifugal action in perforated cylinders revolving at a high speed, the clarifying of the white sugar, and the drying of the white sugar cones in heated rooms by the aid of exhausting pipes communicating with each cone.

A number of Engineering establishments and other works in Paris and the neighbourhood were also opened to the inspection of the Members during the days of the meeting.

PROCEEDINGS.

31 October, 1867.

The General Meeting of the Members was held in the Lecture Theatre of the Midland Institute, Birmingham, on Thursday, 31st October, 1867; Sampson Lloyd, Esq., Vice-President, in the Chair.

The Minutes of the last Meeting were read and confirmed.

The Chairman announced that the President, Vice-Presidents, and five Members of the Council in rotation, would go out of office in the ensuing year, according to the Rules of the Institution; and that at the present meeting the Council and Officers were to be nominated for the election at the Anniversary Meeting.

The following Members were nominated by the meeting for the election at the Anniversary Meeting:—

PRESIDENT.

John Penn, ...	London.

VICE-PRESIDENTS.

(Six of the number to be elected.)

John Anderson, ...	Woolwich.
Frederick J. Bramwell, . . .	London.
William Clay, ...	Liverpool.
Thomas Hawksley, ...	London.
Sampson Lloyd, ...	Wednesbury.
John Ramsbottom, ...	Crewe.
John Robinson, ...	Manchester.
C. William Siemens, ...	London.

COUNCIL.

(Six of the number to be elected.)

Charles Edwards Amos,	London.
Robert Broad,	Tipton.
Edward A. Cowper,	London.
Edgar Gilkes,	Middlesbrough.
Thomas Greenwood,	Leeds.
George Harrison,	Birkenhead.
Edward Jones,	Wednesbury.
William Menelaus,	Merthyr Tydvil.
W. Montgomerie Neilson,	Glasgow.
Charles P. Stewart,	Manchester.
Richard Williams,	Wednesbury.

The **Chairman** announced that the Ballot Lists had been opened, and the following New Members were duly elected:—

MEMBERS.

George Berkley,	London.
George Clark, Jun.,	Sunderland.
Joseph Cliff,	Bradford, Yorkshire.
William Frederick Gooch,	Warrington.
Charles James Homer,	Tunstall.
Frederick James Kimball,	Philadelphia.
James Livesey,	London.
Robert Mallet,	London.
William Martin,	Rouen.
Richard M. Merryweather,	London.
George Blake Oughterson,	Rouen.
Robert Webb Pearce,	Calcutta.
Eugene Sadoine,	Seraing, Belgium.
Patrick Stirling,	Doncaster.
Joseph Taylor,	Birmingham.
Benjamin Walker,	Leeds.
Gilbert Wilkes,	Birmingham.
John Wilkes,	Birmingham.

ASSOCIATE.

WILLIAM THOMAS WATTS, . . Birmingham.

The following paper was then read :—

DESCRIPTION OF THE CROSSNESS PUMPING ENGINES FOR THE METROPOLITAN MAIN DRAINAGE WORKS.

By Mr. GILBERT HAMILTON, of Messrs. James Watt and Co.

These Pumping Engines, which have been constructed at the writer's works, are situated at Crossness Point, where the Southern Outfall Sewer for the drainage of the southern portion of London discharges into the Thames, about four miles below Woolwich. This outfall sewer being at a low level, with its bottom about 8 feet below the mean low-water level, the sewage has to be lifted by pumping, to a level sufficiently high for discharging it into the river soon after high water; the time for discharge is restricted to that period, for the purpose of getting the sewage at once carried out to sea by the ebb tide, and preventing any of it from floating upwards on the river. The sewage is therefore pumped into a large covered reservoir at a higher level, where it is accumulated by continuous pumping during the period of low water and flood tide; and from this reservoir it is allowed to flow out direct into the river, as soon as the time of high water has passed and the ebb tide is running.

The reservoir is shown at A A in the general plan and section, Figs. 1 and 3, Plate 76, and to a larger scale in the section, Fig. 5, Plate 77. It consists of four compartments, each roofed over by eight parallel brick arches of about 15 feet span, carried upon piers about 20 feet apart. The whole reservoir is 560 feet long and 520 feet wide; the average height to the crown of the arches is 17 feet, and the reservoir contains 24 million gallons when filled to a depth of 15 feet, the level of the overflow weirs.

The sewage is brought from the main outlet sewer B, which is 11½ feet diameter, by the low-level culvert C, Figs. 1, 4, and 7, discharging by two branches into the two pump wells D D, situated at opposite ends of the engine house. The sewage on entering passes through an iron grating E E, Figs. 6 and 7, for stopping the entrance of floating timber or other large solid matter, the openings in the grating being 6 inches in width; and it then passes the filth hoist F, which consists of an endless bucket-chain worked by the engine in front of a vertical grating, and intended for separating and lifting out the more solid portion of the sewage into a separate receptacle, to be carted away and utilised. The sewage passes thence to the pumps D D; or when desired it can be admitted direct to the pumps through the second channels G, Fig. 6, by opening or closing the different penstocks.

There are four pumping engines, working independently, and all duplicates of one another, as shown in Figs. 6 to 9, Plates 78 to 81. Each engine works two sets of pumps D D, and each set consists of four single-acting plungers 4½ feet diameter, working in a cylindrical casing of 11½ feet internal diameter. The two outer plungers in each set have a stroke of 4½ feet, and the two inner ones half that stroke.

One of the pumps is shown in section to a larger scale in Fig. 10, Plate 82. The plungers H H are hollow cylinders working through stuffing-boxes, and coupled to connecting rods I I from the engine beam; the connecting rods are coupled in each case to the top of the plunger pole J near the level of the engine-house floor, where the top of the pole works between a pair of vertical guide-cheeks K K, as shown in the sectional plan, Fig. 11. Each plunger pole is made with a long socket-joint piece J, for uncoupling the plunger when not required in action by simply withdrawing the cotter; the socket-piece is sufficiently long to allow of sliding the full length of the stroke without disengaging from the plunger pole. The plunger when disconnected is suspended by two crossbars L L, carried by brackets fixed upon the top of the pump case. The suction valves M consist of a set of leather flaps loaded with wrought-iron plates, and fixed upon a horizontal frame with openings 9 by 18 inches, as shown to a larger scale in Figs. 12 and 13, Plate 83. A crossbar N is fixed over each line of flaps to limit their rise. The delivery valves O O, Fig. 10, are vertical sets of leather flap-valves similar to the suction valves, with openings 12 by 18 inches, as shown enlarged in Fig. 14.

The four sets of pumps worked by two adjoining engines deliver into a covered wrought-iron trough P, Fig. 10, 11½ feet wide and 10 feet high, placed longitudinally between the two engines, Figs. 6, 7, and 8, and discharging at the outer end into the upper-level culvert Q Q, which leads to the reservoir A, Fig. 2. The wrought-iron troughs P P are each closed at the inner end by a penstock; and they are furnished with an air-vessel R, Fig. 10, in the centre of each, for the purpose of easing the action of the pumps when the trough is full and the pumps are working against a head greater than the height of the trough. The work done by the engines in pumping varies very considerably with the height of the sewage in the reservoir, the lowest lift of the pumps being 19 feet when beginning to fill the reservoir, and the highest lift 33 feet when the reservoir is full; the average working lift is about 26 feet.

The contents of the reservoir are discharged into the river by the two middle-level culverts SS about 9 feet wide, shown dotted in the plans, Figs. 1 and 2. These are situated at an intermediate level between the lower supply culverts C C and the upper delivery culverts Q Q, Figs. 3 and 4, and are at a level of 7¼ feet below the floor of the reservoir, so as to drain it completely; the floor has a fall of 2½ feet from the back to the front of the reservoir. Whenever it happens that the tide is low enough during the time that the engines are pumping, the sewage is allowed to flow direct into the river from the pumps through the middle-level outlet culverts SS, without entering the reservoir. The three levels of culverts are all carried along the whole breadth of the reservoir A in the same line C C, Fig. 1, and Q Q, Fig. 2; they are built one over the other, as shown in the sections Figs. 3 and 4, and separated by floors formed of cast-iron girders carrying stone flags. The level of the middle culvert S is 10¾ feet above the lower one C and 8¾ feet below the upper one Q; and the middle culvert S is 2¼ feet above mean low-water level of the river. Each of these three culverts communicates with the reservoir A by a continuous series of lateral openings, Figs. 1 and 2, each 3 feet 3 inches wide and 3 feet 9 inches high, and closed by a penstock. The two middle-level culverts SS forming the discharge outlets from the reservoir are carried out some distance into the river, ending with timber troughs 10 feet wide and 80 feet long, as shown in Figs. 1, 2, and 3.

As a general rule the sluices are opened for discharging the sewage into the river about two hours after the time of high water, except on occasion of the neap tides, when they are opened just after high water. In dry weather they sometimes remain open for only two hours, the ebb tide lasting seven hours; but in very wet weather they are kept open for five or six hours. In the event of a very high tide, the level does not admit of the sewage beginning to run into the river from the reservoir until the water in the river has fallen below the level of the top of the reservoir; such a high tide however does not often occur, the ordinary rise and fall of the tide being about 18 feet. In the case of a very heavy rainfall, as there is not sufficient storage room in the reservoir to allow of adhering to the principle of discharging the sewage into the river after high water only, the engines are then allowed to pump direct into the river as soon as the reservoir is full; in such a case however the sewage is very much diluted with water comparatively pure. This pumping direct into the river is effected by opening the penstocks at the inner ends of the wrought-iron troughs P P, Fig. 6, and letting the sewage flow out through the branch low-level culvert T T, which discharges into the river by the wide mouth U, Fig. 1. This outlet consists of twelve cast-iron pipes, 4 feet 4 inches diameter and 140 feet long, placed at one level in the bed of the river below the low-water line. These pipes form also the direct mouth of the main outfall sewer B, which is ordinarily shut off by a penstock at V, in order to allow of the sewage being led away to the pumps; but it is sometimes opened as the storm outlet, whenever requisite for the discharge of extra storm waters direct from the main outfall sewer.

The pumping engines are shown in Figs. 8 and 9, Plates 80 and 81; they are double-acting high-pressure expansive engines, with single steam cylinders 48 inches diameter and 9 feet stroke, and furnished with a flywheel beyond the pumps, to equalise the motion. Although the pumps are single-acting, the work done in the up and down strokes of the engine is equalised by one set of pumps being placed on each side of the beam centre.

The cylinders are steam-jacketted, and one of them is shown to a larger scale in Figs. 15 and 16, Plates 84 and 85. The valves are of the double-beat construction, the steam valves being $7\frac{1}{4}$ inches and the exhaust valves $8\frac{3}{4}$ inches diameter; they are worked by a cam shaft W having fixed cams X X for the exhaust valves, and a sliding cam Y for the steam valves, in order to vary the rate of expansion according to the work to be done.

The valve cams are shown to a larger scale in Figs. 18 to 21, Plate 86. The exhaust cams X X have a lift of $2\frac{1}{4}$ inches, holding the valve open to nearly the end of the stroke. The steam cam Y has a lift of $1\frac{7}{8}$ inches, with three steps for the different grades of expansion, cutting off at 12, $18\frac{1}{2}$, and 25 per cent. of the stroke. This cam slides upon a feather on the shaft W, and is shifted by means of a toothed sector, Fig. 17, gearing into the outer end of the rod Z which is carried through the centre of the shaft W, Fig. 19. The lead of the steam and exhaust cams, as shown in Fig. 21, is such that at the commencement of the stroke the steam valve is open $\frac{1}{8}$ inch and the exhaust valve $1\frac{1}{16}$ inch.

The steam pressure in the boilers is 35 lbs. per square inch, and the steam is cut off in ordinary working at $18\frac{1}{2}$ per cent. of the stroke when the lift of the pumps does not exceed 20 feet; with a greater lift, up to the extreme of 34 feet lift, the steam is increased to 25 per cent. The working speed of the engines is about 11 revolutions per minute, or 198 feet per minute speed of piston.

Indicator diagrams taken from the four engines are shown in Figs. 22 to 25, Plates 87 and 88; in each case the strong full line is the diagram from the bottom of the cylinder, and the strong dotted line is that from the top. The fine lines show the theoretical true expansion curve, the clearance space in the steam port and at the end of the cylinder being equivalent to an addition of 2·6 per cent. to the length of stroke. The mean pressure per stroke is 6·6 lbs. steam and 12·0 lbs. vacuum, or 18·6 lbs. total, giving 202 indicated horse power for each engine.

The duty of the engines, as ascertained in the official trials made when they had been about a year at work, averaged 86 million lbs. raised one foot with the consumption of one cwt. of Welsh coal, the duty having been designed to be not less than 80 millions. The trials extended over four consecutive days with each engine, the total consumption of fuel and total work done being accurately measured in each case; and the indicator diagrams shown in Plates 87 and 88 were taken at the same time. The particulars of the four trials are given in the accompanying table, the total consumption of coal being 1244 cwts., the average height of lift 20·5 feet, and the average duty 86·4 millions ft-lbs. per cwt. of coal.

Crossness Pumping Engines.
Details of official trials in 1866.

Name of Engine.	Date of Trial.	Duration of Trial.		Coal consumed.	Lift, average height.	Revolutions.	Duty per cwt. of coal.
	1866.	Hrs.	mins.	Lbs.	Feet.	No.	Ft-lbs.
Alexandra......	24–27 April	81	20	35,000	19·220	51,394	85,637,051
Albert Edward	28–31 May	82	43	31,792	22·791	58,424	84,960,460
Prince Consort	11–14 July	81	30	34,914	18·507	52,545	84,546,021
Victoria.........	23–27 July	83	30	37,689	21·482	53,474	92,602,620

The boilers are shown in the plan and section, Figs. 6 and 9. There are twelve boilers, 6 feet diameter and 30 feet long, with a fire tube 3 feet 3 inches diameter at the fire and 2 feet 11 inches in the flue portion; they are set upon two longitudinal walls, with a bottom flue and side return-flues.

These engines have now been at work since 3rd April 1865, and one or more of them is always at work except in very dry weather. In ordinary fair weather the usual amount of working is, one engine alone for 8 hours out of the 12 hours of each tide, and three engines for the remaining 4 hours; but this varies greatly and suddenly with the weather, and sometimes the four engines are at full work together for several hours after a heavy rain in London. The effect of the rain is generally felt at the engines about six hours after it has fallen, which allows time for getting up the steam in all the twelve boilers if necessary, steam being ordinarily kept up in only six of them. A severe rain for a few hours in London generally necessitates the employment of the four engines, and the effect at Crossness is hard work for all four for a short period, and then gradually one engine at a time is knocked off, until the ordinary work of one engine is sufficient to keep the sewage in the culverts at the proper level. On several occasions when there has been an excessive quantity of water, the direct outlet U, Fig. 1, from the mouth of the main sewer B to the river has been used; one instance was on the occurrence of the rapid thaw after the severe frost and heavy snow of last winter. This plan however is only adopted when the sewage comes down in the culverts faster than the four engines can pump; and by this means the sewage in the culverts is reduced to 8 feet depth, that being the lowest level at which it can discharge direct into the river by the outlet U. The four engines when pumping all together discharge 7 million gallons per hour, and are therefore capable of filling the reservoir in 3½ hours, the total contents being 24 million gallons.

The CHAIRMAN remarked that the large engines described in the paper just read were doing a class of work which was at present rather new in this country, but the importance of which was becoming more and more apparent every year; and there seemed no doubt that, before many years had passed by, such works would be very largely extended in different parts of England. He enquired whether the engines now described were the largest that had yet been constructed for the purpose of pumping sewage.

Mr. HAMILTON replied that the Crossness engines described in the paper, with cylinders 48 inches diameter, were of the largest kind yet at work; but a pair of engines were now being put up at the Abbey Mills station, at the outfall of the northern drainage of London, which had cylinders 54 inches diameter. A pair had also been put up at

Deptford with 48 inch cylinders; and all these engines were constructed on very nearly the same plan, being all employed for pumping the sewage of London.

Mr. J. McFarlane Gray enquired what was the consumption of fuel per indicated horse power of the engines.

Mr. Hamilton replied that the engines were working at 202 indicated horse power, and the consumption of coal was about 2·2 lbs. per indicated horse power per hour.

Mr. F. J. Bramwell observed that the practice which originated in Cornwall of stating the duty of engines in millions of pounds raised 1 foot high by the consumption of 1 cwt. of coal had the disadvantage of giving a sort of exaggerated notion of the work done; and this mode of stating the consumption involved the trouble of conversion into the more general one of pounds of coal consumed per indicated horse power per hour. For the purpose of comparison it was convenient to remember that a consumption of 1 lb. of coal per hour, for each horse power of 33,000 lbs. raised 1 foot high per minute, was equivalent to a duty, excluding friction &c., of very nearly 222 millions; and similarly a consumption of 2 lbs. per horse power was equivalent to a duty of 111 millions. Hence the consumption now stated of 2·2 lbs. per indicated horse power per hour would correspond to a duty of about 100 millions; and the actual duty given in the paper being 86 millions, the difference or 14 per cent. was the proportion of power expended in the friction of the engines and the working of the air-pumps &c. A duty of 86 millions was however a very high performance for a pumping engine, and greatly in excess of the pumping engines in Cornwall at the present time, the average duty of which had been decreasing from 68 millions per cwt. of coal in 1844 to 51 millions in 1859; while for the month of August last the average was a little below 50 millions per cwt. of coal, in comparison with the 86 millions performed by the Crossness engines. These engines were therefore a practical proof that a beam engine with crank and flywheel could be made to give as good a duty as engines of Cornish construction, and even a better duty. In the present instance the very low lift at Crossness would certainly be disadvantageous for the Cornish engine, which if used at all should only be employed in the drainage of deep mines, where there was a heavy mass of pump rods to be set in motion at the beginning of each stroke; the inertia of this mass counteracted the sudden large pressure produced by the admission of the high-pressure steam at the commencement of the stroke, while the momentum of the mass when put in motion was afterwards given out during the expansion in the latter part of the stroke.

In reference to economy of working, he thought attention might with advantage be directed to the surprising performance of the non-condensing portable agricultural engines exhibited at the last show of the Royal Agricultural Society at Bury St. Edmunds. These engines were tested by working a friction break loaded by a weight; and the power was arrived at, not by taking an indicator diagram from the steam cylinder, but by the actual load upon the break wheel, so that the result gave the nett effective power, independent of the friction of the engine and break-pulley axle and the slip of the strap. The consumption of fuel with these high-pressure engines was found to be less than 3 lbs. per horse power per hour, as measured by the break; which would be equivalent to more than 74 millions of duty. Such a performance, on the part of engines not possessing the advantage of a large vacuum diagram, was so remarkable, in comparison with other engines which were generally considered to be very economical in working, that he thought the matter was deserving of further consideration. It might be partly accounted for by the very efficient manner in which the cylinders of the portable engines were steam-jacketted, not only all round the sides but also over the covers at both ends; and the steam jackets were so arranged that the steam which became condensed in them was drained back into the boiler. In some of the stationary engines however of the same construction, which when under trial were not worked from their own boiler, the water was not able to run back from the steam jacket into the boiler; in this case it had been considered by some of the exhibitors that it would be a disadvantage to use steam in the jackets, if the water had to be allowed to run to waste; but others with a better appreciation of the functions of a jacket had kept the steam on, and had derived great advantage from its use in the jacket, notwithstanding that the water could not be returned into the boiler but had to run to waste.

In the leather flap valves which formed the delivery valves of the plunger pumps in the Crossness engines, he thought there might be some risk that the flaps might not be all opened at each discharge of the pump, but that a portion only out of the whole number might be opened, and the rest remain constantly closed, without coming into action at all. For it appeared from the paper that the area of opening at each flap was 12 inches by 18 inches (as shown in the drawing, Fig. 14); and if the width of margin all round were $\frac{3}{4}$ inch, this would give an area of about 47 square inches of beating face for each flap. Taking the average head of water on the back of the valves to be equivalent to 12 lbs. per square inch, this with the atmospheric pressure of 14 lbs. would make 26 lbs. per square inch, giving upon the 47 square inches area of facing a total pressure of 1222 lbs. or more than half a ton upon each flap; and to overcome this resistance an extra pressure would be required upon the inner side of the flap amounting to 5·6 lbs. per square inch, in order to lift the valve off the face. In an indicator diagram taken from the pump itself, this extra pressure would not appear as work done, but only as a sudden jump of the indicator at the very commencement of the stroke, because the action was altogether momentary. But he thought this must cause the valves to work with a considerable amount of concussion; and having had several opportunities of seeing the engines at work, he believed that was actually the case. Supposing moreover that some of the valves happened to have a little larger facing than the others, those valves would be the most difficult to drive off their seats; and as the pressure inside the pump was greatly reduced the moment any of the valves were opened, it appeared probable that the flaps which at that moment still remained unmoved might continue closed throughout the whole delivery of the pump, causing the water to be throttled in its passage through the valve openings. Thus if the pressure of 5·6 lbs. per square inch put upon the plungers were sufficient to drive all the water through half of the valve openings, the other half of the flaps might never lift at all during the stroke; and therefore, although a large number of valves were provided, it did not follow that they would all be in action. From these considerations he thought it would have been very desirable to get rid of the large area of facing to each flap, by adopting some other construction or proportion of the valves; and he enquired if any observations had been made as to whether the whole of the valves did open in regular working.

One other point that he wished to allude to in reference to the Crossness engines was the mode of condensation, which he understood was effected by injection, the sewage water pumped up by the engines being used for the purpose. Such a plan must prove detrimental to the engines themselves and to the boilers; and it was matter of surprise that, if nothing but the sewage water itself was available for condensing purposes, a surface condenser had not been applied to these engines, instead of injection.

The highly economical working of the engines, in spite of the disadvantages under which they laboured in the respects that he had referred to, was a most satisfactory result, and reflected the greatest credit upon the makers; and it was to be regretted that they had been restricted to particular arrangements in certain parts of the engines, where there appeared good reason for considering that better plans might have been adopted.

Mr. Hamilton explained that the engines had been constructed in accordance with the drawings and specification supplied for the purpose, and he concurred in thinking that the improvements now suggested would be very beneficial to the working of the engines. With regard to the objection of the large extent of beating face in the delivery valves, he had endeavoured to obviate this by diminishing the width of the beating surface all round the flap to ½ inch or rather less; but it was then found that the wrought-iron plates upon the backs of the leather flaps were broken by the force of the concussion in closing, and it had therefore been necessary to increase the thickness of metal and to widen the beating surface to ¾ inch, which was the present width. There had not been any means of observing whether all the delivery flaps opened at each discharge of the pump; but he did not think that any little irregularities arising from sticking of the valves or from difference of weight in the iron plates would be sufficient to interfere with the flaps all opening at each stroke; because the moment a few of the flaps were opened, the pressure behind the rest was so much reduced that they would be lifted off their faces by a much lower pressure than that required to open the first few flaps.

In reference to the condensation of the steam in these engines, it was certainly the case that at present the dirty water which was discharged into the river from the sewage was being employed as injection water for the condensers; and it was of course highly desirable that such a state of things should be remedied. This was likely to be accomplished shortly, he believed, either by the substitution of surface condensers, with which the sewage water could still be made of service, or by a supply of pure water for injection, pumped from wells which were now in process of sinking to get pure water for the boilers.

Mr. J. McFarlane Gray mentioned that in the case of air pumps attached to marine engines he had met with many instances where much trouble had been experienced from thumping of the valves, and in some engines the air-pump buckets had been found to be broken. On taking indicator diagrams from the air pumps in several instances, the remarkable circumstance was disclosed that the pressure had to be raised in some cases to as much as 24 lbs. per square inch above the atmosphere, or 36 lbs. effective pressure above the vacuum (as shown at A in Figs. 26 to 28, Plate 89), before any delivery took place through the discharge valve; and this necessarily involved a corresponding loss of work in the mere opening of the discharge valve. With the pumping engines described in the paper there was of course no such actual loss of work, as the pumps were always full of water; but there would no doubt be a concussion upon the valves at the instant of commencing the discharge stroke. The difficulty of getting the valves to open promptly and efficiently was not confined to the ordinary flap valves, like those shown in the drawing; but the same was the case with the plain india-rubber disc-valves, now so extensively employed for the air-pump valves in marine engines, and it was to these that the indicator diagrams shown in Figs. 26 to 28 referred. The grids of these valves were now frequently made with round holes drilled with a slight bell mouth, as it was found that the india-rubber disc-valves, particularly when allowed to shift round, lasted longer than with the grid cast in rectangular holes. He thought it very likely that the irregular wearing sometimes observed in large valves might be due to the valve opening irregularly, first at the part where the cover of the valve was the least, and perhaps remaining altogether closed at some other parts.

Mr. C. W. **Siemens** observed that the rise of 24 lbs. per square inch above the atmosphere, mentioned as having occurred in the indicator diagrams taken from the air pumps of marine engines, would certainly be a very astonishing pressure, if it really indicated a corresponding actual pressure in the air pump for opening the discharge valve. But while not doubting the accuracy of the diagrams taken, he suggested that, if there were any considerable length of horizontal pipe intervening between the air pump and the indicator, and containing a column of water, the sudden jump of the indicator (at A, Figs. 26 to 28) might be occasioned by the momentum of this column of water combined with the momentum of the indicator piston itself, at the instant when the orifice of the pipe became covered by the water in the air pump; whereby the piston would be carried up far beyond the point really indicating the pressure in the air pump at that moment. This view seemed to be confirmed by the corresponding deep hollow B immediately following the jump A in the diagrams, which would be occasioned by the rebound of the indicator piston in falling; and he thought therefore that the actual pressure in the air pump at the moment of discharge was probably more nearly that represented by the second and lower oscillation shown at C in the diagrams; the amount of this second rise appeared to him to be quite sufficiently above the atmospheric pressure, not only to ensure the prompt opening of the discharge valves, but to show there must be something wrong in the construction of the valves themselves, that they did not open with a much less amount of pressure.

Mr. J. **McFarlane Gray** did not think the great rise at A in the air-pump diagrams (Figs. 26 to 28) could be accounted for as a mere jump of the indicator piston, occasioned by its own momentum or that of water in the connecting pipe; for an approximate independent calculation of the quantity of water discharged by the air-pump at each stroke showed the space occupied by the water, and the ascending curve in the diagrams being found to form a regular hyperbolic expansion curve up to the point A, the vertical asymptote DE of the hyperbola coincided with the ordinate which marked off the space due to the calculated quantity of water. He accordingly considered that the point A indicated the actual pressure reached in the pump at the moment when the discharge valve opened. The succeeding drop in the diagrams to the point B was no doubt satisfactorily explained by the recoil of the indicator piston, in consequence of the sudden liberation of the compressed air on the opening of the valve; this was followed by a counter-recoil at C, and the average line of these two recoils would show the constant pressure necessary for keeping the valve open to the required extent for the discharge of the water during the last portion of the stroke. The amount of the presssure required for opening the valve in the first instance, as shown at A in the diagrams now exhibited, was no doubt very much beyond what might have been generally expected previous to the evidence afforded by the application of the indicator; but he thought it did not seem excessive when it was considered that the total area of passage afforded by the small round holes in the grid of an india-rubber discharge valve amounted to less than half the area of the valve disc; this alone would require the pressure to be proportionately increased for opening the valve.

Mr. W. **Naylor** remarked that, in reference to the amount of force required for opening the delivery flap valves in the pumping engines described in the paper, he thought a still more important question to be considered was the force exerted to close the delivery valves at the end of the stroke, by the return pressure of the column of water on the back of the valve; and with the size of the flap valves shown in the drawing, with 12 in. × 18 in. openings, he was not surprised to learn that anything less than $\frac{3}{4}$ inch width of beating face all round had been found insufficient in working. An illustration had occurred in his own experience some years ago, of the great amount of force exerted by the return pressure of a column of water in a pump; for in the case of a force-pump erected for pumping water under a pressure of only 36 lbs. per square inch, the delivery pipe frequently gave way at the bottom, close to the pump; and on applying a pressure gauge at that place it was found that immediately after the termination of each stroke the pressure rose to as much as 156 lbs. per square inch, in consequence of the momentum of the returning column of water being suddenly checked by the closing of the valve, so that it acted as a hydraulic ram. In this case the lift of the valve was not more than about 1¼ inch, its diameter being only 5 inches; and therefore as the concussion was so violent on this small scale, it was evidently of great importance that in large pumping engines some provision should be made for gradually stopping the return motion of the water in the delivery main, so as to reduce the violence of the blow in the closing of the flap valves. In the instance he had referred to, an air vessel subsequently fixed between the pump and rising main was effectual in preventing any further accident to the pipe.

Mr. E. A. Cowper quite agreed in the opinion that the concussion produced by the closing of the large flap valves in the pumping engines now described was a far more serious consideration than the slight shock occasioned in opening the valves: it was the plungers returning with the delivery valves still partly open that caused the blow to be so serious; and he was surprised at the flap valves being made of so large a size as shown in the drawings, and thought they would be much better if made considerably smaller. With regard to the use of leather for the beating faces of the valves, he had found in some sewage pumps, which he had put up some years ago, that leather became worn out in three months when used for this purpose, whereas good white vulcanised india-rubber lasted much better, the injurious effect of the blow in the closing of the valves being also lessened by the elasticity of the india-rubber; and he believed therefore india-rubber would have been preferable in the engines now described, and would last much longer than the leather. The plungers being arranged to work in sets of four in one cylindrical barrel or plunger case, there was of course a good deal of space left between them; and the air collected there would be constantly expanding and contracting at each stroke of the plungers, if allowed to remain in the pump, and would thereby occasion a waste of power.

In reference to the excess of pressure necessary to open the delivery flap valves, this was certainly a serious addition to the work to be done by the engine; and in the case of a condensing-engine air-pump he had found by an indicator that the pressure rose to the extent of as much as 3 to 4 lbs. per square inch above the actual delivery pressure, equivalent to an extra head of about 7 feet of water. This was about the amount of the head upon the delivery valve of a marine-engine air-pump, so that in that case the pressure for the time would be doubled; but with the small round holes in the grid of an india-rubber disc-valve, the pressure would have to be increased beyond the 3 or 4 lbs. corresponding to that head, in consequence of the greatly diminished area of passage through the valve. He did not think however that round holes were now usual for the grids of such valves, but believed the gratings were generally made with narrow rectangular openings, the grid bars being rounded on the top surface; by this means the excess of pressure necessary to lift the india-rubber disc off the bars was reduced to a minimum. He had had india-rubber valves in excellent condition after four years' wear.

With respect to the indicator figures taken from the steam cylinders of the engines described in the paper, he enquired what had been the reason for carrying the expansion to so great an extent in a single cylinder, considering that in the present instance the low lift of the pumps did not admit of the heavy weight of pump rods, which in the ordinary Cornish engine constituted the main ground for the high degree of expansion there employed. He suggested that if the indicator figure had been cut in half, and the expansion performed by means of a double-cylinder engine expanding to half the extent in each cylinder, the strain upon all the parts of the engines would have been much less, and the present enormous flywheels of 50 tons weight would not have been wanted. He understood in fact that the flywheels were at first intended to be only 25 tons weight; but they had been made of 50 tons weight, in order to be capable of absorbing the excessive amount of power which was thrown into the wheel by the extreme pressure on the piston at the commencement of each stroke. The same amount of power had to be given out again by the flywheel at the close of the stroke; and there could be no doubt therefore that this constant transfer of such large amounts of power at each stroke must throw a very great strain upon the beam, connecting-rod, pump rods, and foundation, and must seriously increase the cost of maintaining the engine. He thought a cheaper engine, with much less strain upon the parts, might be made, requiring considerably less power to do the same amount of work. From the experience of a pair of single-cylinder engines which he had made many years previously, he was satisfied that it was not advantageous to expand beyond a certain moderate extent in one cylinder; whereas in other engines having two cylinders he had found no difficulty in carrying the expansion further than in the engines now described.

As to the use of the sewage water for the injection in the condenser, he thought there could not be two opinions as to the objectionable nature of such a plan; and with the advantage of an unlimited supply of the cold sewage water pumped up by the engines, it certainly seemed very desirable to substitute surface condensation, whereby a supply of pure water would always be returned to the boilers. Moreover with a surface condenser there was the further advantage that at least another inch of vacuum was gained, as compared with an injection condenser.

Mr. J. McFarlane Gray explained, with regard to the holes in the gratings of india-rubber valves, that although narrow rectangular holes had been extensively adopted for the purpose, the round holes were now more generally employed in the case of marine-engine air-pumps, because it was found that the grids with rectangular holes were liable to become cracked through at the corners of the holes, particularly in the air-pump buckets. In the repairs of marine engines he had frequently been called upon to replace the original grids with rectangular holes by new ones with round holes, at the request of the engineers in charge of the vessels. It was also found that the round holes had the advantage of not cutting the india-rubber so much as rectangular holes did.

Mr. **Hamilton** said that, respecting the comparative durability of india-rubber and leather for the beating faces of pump valves, his own experience did not enable him to state which material was the best. He had found india-rubber a very perishable article, wearing away very rapidly, and indeed under ordinary pressures much more rapidly than leather. For work of the kind described in the paper he believed leather was best; and he had met with cases in which india-rubber had not lasted more than a month for similar purposes. The flap valves for the delivery from the pumps shown in the drawing were no doubt of large size, and it might perhaps be more economical, in regard to the wear of the beating surfaces and the force required to open the flaps, if they were made of a smaller size; but the difficulty then would be to get the requisite area of passage for the quantity of water discharged by the pump.

In reference to the suggestion that only a certain number of the flap valves might open for the passage of the water, while the rest might remain shut, he doubted greatly whether that was ever the case in reality, and he believed that in fact all the valves did open. The india-rubber disc-valves, which had been spoken of so favourably in connection with marine-engine air-pumps, would certainly not have been suitable for the present purpose; because a large portion of the area at the centre of each disc, where it was held down tight to the grid, was practically useless for the passage of the water, and the rise at the circumference of the india-rubber disc gave an area of passage which was generally only about one quarter of the area of the disc itself. Moreover the vacant spaces left between a number of the circular india-rubber valves would reduce the area of passage at least one third in the first instance; for in punching out the blanks for coins in coining presses, it was found that, when the holes were punched as close together as practicable, there was still fully one third of the metal left behind. On these accounts, notwithstanding the disadvantages of flap valves, he preferred to use them for the delivery valves of the pumping engines described in the paper; and for the same reasons he also continued to use flap valves for the air-pump foot and delivery valves of condensing engines, except in the case of marine engines, where the india-rubber disc-valves were employed on account of their easier action for a quick speed. The most serious objection to the flap valves he considered was the injury done by the back blow of the flaps in closing, which destroyed the material of the beating faces, whether india-rubber or leather.

No difficulty had been experienced from accumulation of air in the pump case in which the plungers worked, nor were air cocks found necessary for getting rid of it. Any air making its way to the top of the case escaped through the stuffing-boxes of the plungers, which were not air-tight, although packed tight enough to prevent leakage of water.

With regard to the use of double cylinders, for the purpose of obtaining the same degree of expansion in two stages, the experience of the working of the double-cylinder engines at the New River Water Works had led to the conclusion that the single cylinder was best. A double-cylinder engine was much more complicated in construction; and the extra expense of keeping it in order, in consequence of the greater number of parts exposed to wear and tear, as well as the extra friction, was considered objectionable. In the engines now described, the object was to get the greatest amount of expansion possible in a single cylinder, using of course a proportionately heavy flywheel to equalise the motion.

Mr. B. P. WALKER enquired whether any comparison had been made between centrifugal pumps and pumps such as those described in the paper, and what was the comparative value of the two in raising large quantities of water.

Mr. HAMILTON replied that he had made a number of careful experiments with centrifugal pumps, and he believed the duty done by the engines now described was quite double that performed by the best centrifugal pump.

The CHAIRMAN moved a vote of thanks to Mr. Hamilton for his paper, which was passed.

The following paper was then read:—

DESCRIPTION OF AN IMPROVED STEAM PILE DRIVER WITH ENDLESS CHAIN.

By Mr. PETER B. EASSIE, of Gloucester.

The Steam Pile Driver forming the subject of the present paper belongs to the class of endless-chain pile drivers, which have now come into extensive use for large works both in this country and abroad, being found to possess an important practical advantage in the continuous motion of the chain running always in the same direction; in consequence of which the engine never requires to be stopped or reversed during the performance of the work, nor are any reversing clutches required for reversing the motion of the crab winding the chain. The object of the writer in designing the improved pile driver about to be described has been to remove some defects in detail that are involved in the ordinary construction of endless-chain pile drivers.

The chief improvement aimed at in this pile driver has been to lift the ram by its centre of gravity, and thus reduce the friction on the front and back of the leaders. In the pile drivers hitherto in use the ordinary mode of attachment of the lifting chain to the ram has been as shown in Figs. 4 and 5, Plate 91, where the attachment of the ram A to the chain C is at the back of the leaders B; and the ram is released either by withdrawing the catch D, as shown in Fig. 4, or by throwing out the chain from the catch by an inclined stop E, as shown in Fig. 5. Although the effect of the blow when the ram is released is the same as with any other mode of attachment, the friction in lifting is excessive, in consequence of the nipping action at front and back of the leaders, arising from the canting of the ram against the leaders; and this binding effect increases in intensity the greater the distance of the point of attachment from the line of the centre of gravity of the ram. This friction has been ascertained by experiment to amount to nearly one fourth of the whole weight of the ram, so that in lifting a ram of 1 ton weight the force required to be exerted amounts to $1\frac{1}{4}$ ton, in addition to that required to overcome the inertia of the machinery.

Another improvement is the introduction of springs to reduce the intensity of the sudden strain caused by the weight of the ram being thrown suddenly on the chain, in consequence of the lifting hook engaging in the chain while moving at a considerable velocity. This is an essential provision for preventing injury not only to the chain itself, but also to the general framing of the machine, by preventing shocks to the framing at the moment of commencing to lift the ram.

The improved pile driver is shown in Figs. 1, 2, and 3, Plates 90 and 91. Fig. 1 is a side elevation of the pile driver driving a raking pile; and Fig. 2 a side elevation, partly in section, of one driving an upright pile; Fig. 3 shows a front elevation of the machine. Figs. 6, 7, and 8, Plate 92, show the ram of the pile driver in the act of being raised in Fig. 6, at the moment of being released in Fig. 7, and in Fig. 8 it has just fallen and struck the blow.

The ram A, shown to a larger scale in Figs. 9 to 11, Plate 93, weighing from 15 to 30 cwts., slides freely between the leaders B B, being kept in position by the two clamp bolts G G, which fit into slots in the ram, and have eyes at the back for the lifting chain C to pass through, Fig. 6. The steel hook H, for lifting the ram, is jointed on the top of a rod passing through the centre of gravity of the ram; and is constantly pressed inwards by a small spiral spring I, so as to engage in the links of the lifting chain C. The attachment of the lifting rod to the ram is made with springs J J, in order to ease the sudden strain occasioned by the weight of the ram being thrown suddenly upon the chain. India-rubber springs are found to serve this purpose the best, steel volute springs having been found liable to break, as the space through which the lifting rod has to yield amounts sometimes to as much as 2 inches when the chain is driven at its greatest speed.

The lifting chain C, passing up through the eyebolts G at the back of the ram, Figs. 6 to 8, is brought forwards to the front of the leaders B and into the line of the centre of gravity of the ram by means of the "follower" F, which consists of a light iron frame carrying the roller F and sliding freely between the two leaders B B, as shown to a larger scale in Figs. 18 to 20, Plate 94. During the ascent of the ram, the follower rests upon the top of it, and is carried up with it, as shown in Fig. 6; and as soon as the lifting hook H has been disengaged from the chain by the "striker off" K, Fig. 7, the ram falls and gives the blow, as in Fig. 8, and the follower runs down after it as rapidly as the friction of the chain in passing under the roller F will allow. The slight retardation thus produced in the descent of the follower is sufficient to allow time for the rebound of the ram after striking the blow to cease, before the follower overtakes it; and an india-rubber buffer-spring fixed in the bottom of the follower reduces the shock of the follower falling upon the ram. The roller F of the follower is made of wood hooped with iron, and revolves freely between the side plates of the follower; while the sloping fender-plate L prevents the slack of the chain from accumulating at the follower. The follower is guided between the leaders B B by four strips of angle iron rivetted on the side plates, as shown in the plan, Fig. 20; and as soon as the follower overtakes the ram, it brings the lifting chain within reach of the hook H, which instantly engages in the chain again, and the ram is again raised as before.

In most other pile drivers worked by an endless chain it is found in practice that the ram is liable to be caught again by the chain while it is in the act of rebounding after the blow has been struck; and this has doubtless been the cause of the trouble hitherto experienced with these machines, from breakages of the chain and injury to the wood framing of the pile driver. But with the above arrangement, as the ram falls freely, while the follower is retarded in its descent by having to run down the chain, there is time allowed for the ram to cease rebounding off the pile, before the follower can again attach the chain to it. The result has been that, during the whole of the writer's experience with the improved pile drivers, not a single breakage of the lifting chain has occurred, with the exception of the machine first made, which was used in driving cast-iron piles, when the lifting chain was found to be too weak.

The "striker off," for disengaging the ram from the lifting chain, is shown in Figs. 15 to 17, Plate 94, and consists of an iron framing somewhat similar to the follower, on the front of which are centred a pair of bell-crank levers carrying a roller. When the engaging hook H of the ram comes in contact with this roller, it first raises the levers and gives them a nipping action upon the leaders B, whereby the striker-off is held tight in its place and prevented from being lifted by the ascent of the hook; and then the roller K bearing against the tapered extremity of the hook, as shown in Fig. 7, disengages the hook from the lifting chain C, and the ram falls freely. The height of fall is regulated simply by raising or lowering the striker-off by the cord M, which passes over a pulley on the top of the leaders, the end of the cord being secured within reach of the engineman.

The endless pitch-chain C, Fig. 6, by which the ram is lifted, is shown to a larger scale in Figs. 12 to 14, Plate 94, and consists of double and single links alternately; the lifting hook of the ram engaging in the spaces left between the double links. The links are curved on the edges to fit the rollers over which the chain runs. The pins are of steel, and the middle portion passing through the centre link is made of rather larger diameter than the two ends, leaving a shoulder against which the outside links are rivetted on tight, so that the centre link can work freely on the pin. At about every 8 feet in length of the chain a screw pin is used instead of a rivet, for facility in putting the chain together, or for taking it to pieces in case of repairs.

During the working of the pile driver, the chain is kept constantly running in an upward direction in front of the leaders, for lifting the ram. It passes over the pulley N, Figs. 1 and 2, at the top of the leaders, and thence down to the pitched wheel O on the main shaft of the crab; then under a guide roller in the platform of the machine, and up behind the leaders to the follower F, by which it is again brought in front of the leaders above the ram A. The chain is tightened or slackened as required by means of adjusting screws regulating the position of the top pulley N. In practice it is kept slack enough to allow of the follower F descending readily by its own weight after each fall of the ram.

The whole machine is carried on a platform P, Figs. 1 and 2, having at each corner double-flanged wheels, so that the pile driver can be moved easily in either direction on rails laid down for the purpose. On this lower platform is carried an upper one, turning upon a centre pin like an ordinary turntable, so as to allow the pile driver to be faced to any of the four sides of the machine. Anything that adds to the handiness of a pile driver is always found advantageous, and this simple turntable increases the efficiency of the machine and often saves considerable time. On the upper platform are hinged the leaders B and side stays, connected by framing to the back ladder Q, at the foot of which there is a strong adjusting screw and guide R, allowing the pile driver to be set to any inclination up to 1 in 6 when required, in order to drive raking piles, as shown in Fig. 1. The boiler is an upright one, and the engine is placed vertically with the cylinder inverted, working down upon the crank shaft, on which is the pinion driving the crab O. The large shaft of the crab carries a double clutch-box, having on one side the chain drum for lifting the pile, and on the other side the pitched wheel driving the endless chain C which raises the ram. A break is provided, so that either the pile or the ram can be lowered gently at any time. The boiler, engine, and steam crab, being on an independent base-plate, are available for other purposes, such as hoisting, pumping, and other operations required on large works; and they are complete for these purposes, whether that portion of the machine used in pile driving is taken away or not.

Next in importance to obtaining a pile driver which will work economically in respect of fuel, and having also a sufficiently long range of fall that can be easily increased or diminished, is a quick and ready means of transporting the machine from pile to pile. With this view the weight of the whole machine itself has to be reduced as far as practicable, by making all the component parts as light as possible, consistent with its general efficiency. In large engineering workshops, where heavy weights are constantly being lifted and removed to different machines, various descriptions of traversing cranes are adopted, so that the heavy masses can be deposited at any point of a large space commanded by the traverser. A pile driver mounted on a traverser of this description is always a sure source of economy in such works as piers running out to sea, or pile foundations for walls; the traverser being made to span the full width of the pier or wall, so that the pile driver can be easily moved to any position commanded by the traverser. Thus in the case of driving piles level with the ground for the foundation of a wall, supposing that in the breadth of the wall there are four or more rows of piles, the writer is satisfied that, by laying rails outside the field of operation and using a traverser with a pile driver moving transversely upon it, a saving of one third the labour expended in driving the piles by the ordinary machine can be effected, owing solely to the time taken up in moving the latter from one pile to another. Similarly in the case of timber piers running out to sea, if the number of piles to be driven be sufficient to warrant the extra outlay incurred, a large saving is effected by erecting gantries on which a traverser may run, carrying a pile driver moving across it, so as to command the whole space of operations. These gantries are then still available also for all other operations; so that pile driving, dredging, and lifting heavy weights can all be carried on simultaneously.

The pile driver shown in Figs. 21 and 22, Plates 95 and 96, is of this class, and is called a "telescopic pile driver," being designed not only to command a large area and put down a pile readily in any position included by the line of rails on the gantries S S, but also to drive piles 30 or 40 feet below the level of the rails on which it traverses. It is thus of great value in running out piers in deep water or driving piles in trenches. Figs. 21 and 22 represent the nature of the work that had to be done by the first pile driver of this construction, which was adopted by the Admiralty for driving piles in trenches in the extension works at Chatham. In this case the trenches were cut out of soft clay and other yielding materials, so that the sides required supporting by means of the struts T T; and it was therefore necessary that in traversing longitudinally over the trench the pile driver should pass clear above the struts T.

The traverser U is mounted on wheels running upon the rails laid on the gantries S S. The longitudinal traverse is effected by means of the shaft and pinion V, driven by the engine of the pile driver; and the cross traverse of the pile driver upon the traverser is effected by chain gearing from the steam crab. A pile can then be driven in any portion of the space comprised within the gantries; and the traverser overhangs the gantry on one side at W, so that the piles may be driven close to that side of the trench as well as the other.

In order to drive a pile to the bottom of the trench, a long frame X X is introduced, called the "needle," sliding freely between pieces of T iron fastened on each edge of the leaders B of the pile driver. This frame is raised and lowered by the chains Y, attached to each side of it and winding upon a drum on the steam crab; and it serves as the guide for the ram and follower, in place of the leaders themselves. The plan usually adopted is to fasten the lower end of the needle X to the head of the pile, as shown in Fig. 22; or the needle may be lowered at once to the bottom of the trench, as in Fig. 21. After the pile has been driven, the needle is raised clear of the struts T or level with the rails, and the machine can then be traversed in any direction longitudinally or transversely, the whole of the movements and the lifting of the needle being effected by the steam power on the platform of the pile driver. The leaders and side stays of the machine are hinged, so that they can be adjusted for driving raking piles with the needle, as shown in Fig. 22, with the same facility as in the construction of pile driver previously described. The endless pitch-chain C is connected solely to the needle X and steam crab O, and as it never requires in practice to be stretched perfectly taut, it is always ready for immediate use, whether the needle is raised to the top or lowered to the bottom of the trench.

The cast-iron pile shoes shown in Figs. 23 to 32, Plate 97, were designed by the writer for the purpose of affording a broad base to the wood of the pile itself, and also with a view to economy of space in packing for export. The shoe shown in Figs. 23 to 26 is for an ordinary square pile, and that in Figs. 28 to 32 for a sheet pile; consisting in each case of a hollow casting forming the toe of the pile, with dovetailed recesses cast on for the attachment of the wrought-iron straps, Fig. 27, which after being adjusted are fastened to the pile by spikes in the ordinary manner. All the dovetails and the ends of the straps being made alike, they are readily attached, and are found in practice to take up considerably less room in stowage than any other construction; while owing to there being no holes at the point of attachment, the straps can be made smaller in size and thus reduced in cost. Before being used, these hollow shoes are sometimes filled up with cement or some other material easily obtained at the site of the work.

The accompanying table gives the particulars of half a day's work with one of the telescopic pile drivers employed at Cardiff Docks. Some difficulty was experienced in this case in getting at the exact height of fall of the ram, as the machine was at work upon gantries, driving piles in water; but the fall was ascertained to be on an average about 10 feet. The last 40 or 50 blows were given with a fall of 14 feet, causing the pile to go down from 1-8th inch to 3-16ths inch per blow. The weight of the ram was 21½ cwts.; and the size of the piles was 13 inches square, and their average length 46 feet.

Telescopic Pile Driver at Cardiff Docks.

	Length driven.	Total No. of Blows.	Time occupied.			Mean Steam Pressure.
			Setting.	Driving.	Total.*	
	Feet.	No.	Mins.	Mins.	Hrs. mins.	Lbs.
Pile No. 1	35	113	40	40	1 28	42
– No. 2	27	140	30	35	1 18	45
– No. 3	32	130	50	34	1 50	43
Average	31	128	40	36	1 32	43

* Total time occupied, including all delays.

The average result of the observations made upon the driving of these three piles in succession was that the number of blows required to drive each pile to a depth of 31 feet was 128 blows, and the time occupied in actually driving was 36 minutes; the total time spent in driving the three piles, including all delays, was about 4½ hours. The men employed were one engineman and three labourers; and the consumption of coal was about 3½ lbs. per foot depth of pile driven, or 3 lbs. per foot cube, the total cost of driving being 3*d.* per foot depth, or 2½*d.* per foot cube of pile driven.

Mr. **Eassie** exhibited in action a working model of the pile driver, together with specimens of the hollow cast-iron pile shoes.

The **Chairman** enquired how long the improved pile drivers had been in use, and how many of them were at work at the present time; and also what was about the cost of working as compared with ordinary pile drivers.

Mr. **Eassie** replied that seven of the pile drivers had now been made, and they had been in use during the last two years. The telescopic pile driver, which was the last modification of the plan, had been specially constructed for driving piles in a trench at the dockyard extension works at Chatham, for the foundations of a wall intended to surround an island; and the operations had been commenced by first driving two rows of piles for carrying the gantries (as shown at SS in Fig. 22), which was accomplished with an ordinary pile driver. The trench was then excavated 20 feet deep and 25 feet wide by an excavating machine running upon the gantries; after which the piles 12 inches square for the wall foundation had to be driven in flush with the bottom of the trench in rows of four piles across the trench at every 10 feet length, while the space in front of the wall and between each main pile was filled in with a continuous row of 6 inch sheet piling. The mode at first employed for driving these piles was by placing a common pile driver upon struts in the trench, and working it by means of a separate stationary engine on the bank; and the pile driver had to be shifted by hand labour for each separate pile that was driven. It had therefore occurred to him that, by making use of the gantries previously erected, a great saving both of time and labour would be effected, if the pile driver were placed upon a traveller running upon the gantries, and so arranged as to drive the piles at the bottom of the trench. The telescopic pile driver was accordingly constructed for the purpose, having the sliding frame or "needle" extending below, which followed the pile as it sank in the ground, and afforded a guide for the ram to the very bottom of the trench. This arrangement commanded the whole space of the trench; and also conveniently allowed of driving one of the piles on a batter in each row of four, as shown in the drawing, which was generally the case for walls of that sort, the other three piles being driven vertically.

The result of the working of this pile driver at Chatham had been that a very great saving was effected, the previous cost of the same work having been as much as 6*d.* per foot depth of pile driven, whereas the cost after the adoption of the new machine was reduced to only 1½*d.* per foot depth. The rate of working was usually about 8 blows per minute with 8 feet height of fall of the ram. The table of experiments appended to the paper gave the results recently obtained in the working of one of the pile drivers at Cardiff, where it was employed for driving piles in the sea for the dock works; and in this case the total cost of working was shown to be about 3*d.* per foot depth of the piles driven.

Mr. E. A. Cowper thought the arrangement of the follower in the new pile driver, for bringing the chain forwards from the back to the front of the leaders, was very good, so as to provide the means of quickly picking up the ram by a simple self-acting contrivance, which had always been a difficulty in previous machines. There was of course a slight loss of effect from having to raise the follower itself, without making use of its weight for increasing the blow of the ram in falling; but he thought this slight sacrifice would be more than counterbalanced by the important advantage of the very short time of standing after each blow, before the ram was again picked up by the chain. The follower descended so speedily after the ram, and attached it again to the chain with so short an interval from the moment when it had been released for the blow, that there was not time enough for the engine to run off; and it was therefore not necessary to turn off the steam between each blow, as was the case with ordinary pile drivers. He enquired what was the weight of the follower itself, and what might be reckoned upon as the comparative saving in cost of working by the new pile driver over the ordinary hand machines. In regard also to the average rate of working which had been mentioned, of 8 blows per minute with 8 feet height of fall, he enquired whether that might be taken as the average rate also in the case of great differences in height of fall, as for instance with a very high or a very low fall. He thought the machine promised to be very successful.

Mr. **Eassie** replied that 8 blows per minute with 8 feet height of fall might be taken as a fair average of the rate of working of the pile driver; during the time of observation with the machine in use at Cardiff the average height of fall had been 10 feet, increased to 14 feet in the last 40 or 50 blows on each pile. The cost of working he thought might safely be taken at only about one quarter of that with a hand pile driver, if there were a large number of piles to be driven and the work was straightforward; for in such a case the employment of the new pile driver would cost only about 1½*d.* per foot depth of pile driven, as compared with 6*d.* per foot depth for driving the same piles with one of the hand machines. The weight of the follower was from 110 to 115 lbs., and it was provided with a buffer spring on the underside, to reduce the concussion in falling on the ram.

Mr. W. **Naylor** observed that it was not so important in pile driving to obtain a great height of fall for the ram as to get sufficient weight in the ram itself; this was clearly illustrated by taking an extreme supposition of a weight of 1 lb. falling through 10,000 feet, and a weight of 10,000 lbs. falling through 1 foot; the power exerted for raising the weight would be the same in both cases, amounting to 10,000 foot-pounds, but the velocity acquired by the lighter weight being 800 feet per second whilst that of the heavier weight was 8 feet per second, the momentum of the heavier weight would be 100 times that of the lighter, and the blow would consequently be 100 times as effective. A remarkable instance that he remembered meeting with many years ago, of the inefficiency of a high fall and light ram, was in the construction of the Southampton docks, where the walls were built upon piles 14 inches square, which had to be driven through a bed of stiff blue London clay. For the last portion of their length a ram of 1 ton weight was employed with 20 to 25 feet fall, and it was intended to drive the piles home solid; but when nearly driven the whole length they began to stop going down, and although the top of the pile went down under each blow of the ram, it sprang back again immediately after the blow, and the pile itself was driven no deeper into the ground, however long the work was continued. It was then found, on making an excavation at one of the piles, that about a couple of feet below the surface of the ground the solid timber was completely shivered in all directions into fine splinters. To obviate this defect, a heavier ram was substituted, of 2½ tons weight, and the height of fall was reduced to 8 or 10 feet, so that the power expended in working the machine remained exactly the same as before; but the difference in the momentum now obtained changed what had been a merely destructive blow into one which was really effective in driving the piles, and by means of this heavier ram the rest of the piles were driven solid into the ground with complete success. The mistake of using too light a ram for driving piles was in fact only less absurd than attempting to perform the same operation by firing bullets from a musket.

The CHAIRMAN moved a vote of thanks to Mr. Eassie for his paper, which was passed.

The following paper was then read:—

DESCRIPTION OF THE STEAM STEERING ENGINE IN THE "GREAT EASTERN" STEAMSHIP.

BY MR. J. MCFARLANE GRAY, OF LIVERPOOL.

It is now more than half a century since the first establishment of Steam Navigation in this country, and during that time great improvements have been effected in the construction and propulsion of steam vessels; but the appliances for Steering large steamers are still almost identically the same as those employed in the wooden ships previous to the introduction of steam. It is remarkable that this should be the case, considering that the modifications in the form of hull, the increase of speed, and the absence of sails, all resulting from steam propulsion, render the steering not only of more importance but at the same time more difficult. In some of the armour-plated ships in the British navy, it requires nearly a hundred men to put the helm hard over when the vessel is going at full speed; and except with twin screws the action of the rudder is the only force that can be applied to change the course of a steamship. The handiness of the vessel and its safety, especially in a war steamer, depend upon being able to manœuvre it quickly; and hence it is of the first importance that a steamer should be provided with as much steering power as possible. This has hitherto been limited by the power at command for moving the rudder; and in the merchant service the increase of force required has been provided at the expense of time by introducing gear with a greater mechanical leverage. Where collision is imminent, the power required for quick steering being wanting, the engines have to be reversed, whereby the danger is often increased; the vessel continues to advance even after the engines are reversed, until her way is stopped; and it requires some time to reverse first the engines and then the motion of the ship itself. Under such circumstances the best security would generally be found in a quick steering gear, which would quietly and with certainty alter the ship's course, without the confusion always created by a sudden order to reverse at full speed.

The work of steering a ship is one which requires in regular sailing only a small expenditure of power; but it is necessary occasionally to apply a great amount of force for the purpose, and arrangements should be made that this may be applied at any instant without distracting the attention of the steersman or requiring any special exertion on his part. The whole of this force, whatever it is, should be always at hand, and always on duty, so that there may be no loss of time and no uncertainty in its action.

With the economy of labour necessary at sea, the amount of manual power required for steering is not always available at the moment when needed, and sometimes there is only half the steering power at the wheels, while the other half is employed in other parts of the ship. In a recent case of collision at sea one of the witnesses stated that, being on deck when the order was given for hard-a-port, and hearing it repeated a few seconds afterwards, he went into the wheel-house to help to put the rudder over. It is apparent that such a case ought not to occur at the present day, and the steering ought to be so controlled that no order should have to be given twice. Even indirectly this would add greatly to the safety of the ship, for it would free the officer in charge from the distraction of mind produced by the uncertainty as to whether his order was being obeyed or not, and would leave his whole attention free for the further orders required.

In addition to the want of power which has all along been experienced in the steering of large steamers, there has also been considerable risk of injury to the men at the wheels. They have had not only to put the rudder over to a certain place, but also to keep it there as long as required; and they have also to keep the rudder amidships when required. In general there is such an amount of slack in the gear that the rudder cannot be held steady in any position unless the water is exerting some force against it.

When nearly amidships therefore and in rough weather, the pressure on the rudder is continually changing from one side of the rudder to the other; and when struck by a wave on the opposite side, the rudder moves rapidly a short distance until it is checked by the steering gear. These changes are quick, and tiring to the men; and when the force of the wave happens to come suddenly in the same direction as that in which they are exerting their force, the wheels sometimes fly round, knocking the men down, or throwing them over the wheel altogether; and broken limbs and many fatal injuries have been caused in this way.

The steering of a ship is effected at the stern, which is the very worst position on the deck for a look-out; and this objection has therefore been met in two ways. In some ships the chains or ropes for moving the rudder are led from the stern to some more convenient station about the middle of the ship; and in others the steering is controlled from the bridge at the middle by telegraphing to the men at the wheels. The first plan is inconvenient, and exposes a long stretch of rope or chain to a great strain; and steering by telegraph, however well arranged, always involves a little delay, and is not so certain in its action as direct steering.

From these considerations it is evident that every steamship ought to have a quick and direct steering power; that this power should be always on duty, and always to its full amount; that it should be certain in its action, requiring no second order; that it should not expose the men to danger; and that it should be controlled from the bridge or other suitable station on the deck. The consequence is that in steamers over 1000 tons burden these conditions can be fulfilled only by the use of steam power.

The want of a Steam Steering Engine was from the first felt in the case of the Great Eastern steamship, but until the present year the vessel was steered by manual power alone; and the danger to which she was exposed on a former occasion by the accident to her rudder stock was the result of want of power at the wheels, the men not being able to keep the rudder in check. The automatic steam steering engine forming the subject of the present paper was designed by the writer, and constructed for the Great Eastern by Messrs.

George Forrester and Co. of Liverpool, under the inspection of Captain Sir James Anderson; and the following conditions were required to be fulfilled in its construction:—

1st. The alterations on board the vessel to consist of additions only, and no existing appliance for steering to be removed or impaired.

2nd. The steam power to be sufficient for moving the rudder at all times at a greater speed than had ever been attained by manual force.

3rd. The steering to be controlled from the bridge by some means equal in efficiency to the existing telegraph plan.

4th. The new arrangements to admit of men working at the wheels in order to assist the steam power if required.

5th. The steam gear to be capable of being disconnected without interfering for an instant with the means of steering by hand.

6th. The rudder to be held in any position by the steam gear without applying a break.

7th. The engine to start without hesitation at all times, even after standing for a considerable period without acting.

8th. The apparatus to be simple in all its parts and requiring no special attendant or engineer.

9th. The engine to be capable of being used as a windlass if required, when disconnected.

The Automatic Steam Steering Gear actually constructed fulfilled all these conditions, and in several respects far exceeded the requirements. It is shown in Plates 98 to 105, Fig. 1 being a longitudinal elevation and Fig. 2 a general plan showing its application on board the Great Eastern.

The steering gear consists of an engine A, Figs. 1 and 2, connected to the shaft of the original steering-barrel B at the stern, and controlled through a shaft C by a small steering-wheel D at the bridge. This wheel is so arranged that the steering-wheels EE at the stern revolve turn for turn with it, and the steersman at the bridge directs his attention, not to starting or reversing the engine, but simply to steering the ship by the bridge steering-wheel D, leaving the engine entirely out of consideration. There is an index at this wheel D showing the position into which the rudder is required to be brought; and at the stern there is another index with a director arm, which serves as a steering telegraph dial when steering by hand. There is also a spare controlling wheel Z at the engine A, so that the steering by steam can be controlled from the stern if required. The steering-barrel B, the chains FF, and the tiller G, remain exactly the same as before the alteration, and are worked direct by the steam steering engine.

The engine itself is of the simplest construction, as shown in Figs. 11 to 13, Plates 104 and 105, having a pair of cylinders working cranks at right angles; and the reversing, stopping, and starting are effected by the automatic stop-valve H, which is a hollow cylindrical slide, covering both the steam and the exhaust passages, so that according to its position it can reverse the action of these passages, thus making the engine go in either direction by changing the exhaust into steam passages and the steam into exhaust. The two slide-valves are the same in form and dimensions as this stop-valve, and are worked by fixed eccentrics set on the driving shaft S, Figs. 5 and 8, each at right angles with its crank; the travel of each slide-valve is 2½ inches.

The automatic stop-valve H does not work with the engine, but is controlled by the differential screw I, Figs. 6 and 8, which constitutes the self-regulating portion of the steering gear. The stop-valve is connected to the screw I by a rod and bell-crank lever, so that the longitudinal motion of the screw is communicated to the stop-valve. The pitch of the screw is 1¼ inch, and the range of its longitudinal travel is 2½ inches, being equivalent to two revolutions of the screw in its nut J, which is itself incapable of longitudinal movement. This nut however is not held stationary from turning, but is formed in the centre of a mitre wheel, which is geared with an equal wheel on the rudder-shaft K, so that the nut makes one revolution for each turn of the steering-barrel B. The differential screw I has a spur wheel on it, which gears with an equal but broader spur wheel L on the telegraph shaft C, Fig. 5, led from the bridge steering-wheel, so that the screw I revolves turn for turn with the controlling wheel D at the bridge. It is obvious therefore that, the screw I being thus connected with the telegraph shaft C from the bridge, and the nut J with the rudder-shaft K, the actual movement of the screw longitudinally will not be governed by either of these independent of the other, but will be affected by both, and will correspond always to the difference between the motion of the steering-wheel and of the rudder-shaft, the screw being thus a differential apparatus. If the nut J be held stationary while the screw I is turned, the latter will travel endways in the nut; but if at the same time the nut be made to revolve in the same direction and at the same speed as the screw, there will be no end motion of the screw.

When the engine is at rest, the steam stop-valve H stands in its middle position, as shown in Fig. 11, closing the cylinder ports entirely both to the steam and to the exhaust. If the telegraph shaft C be now turned, Fig. 5, the screw I being thereby also turned will travel endways in the nut J; and this end motion will be communicated by the lever to the stop-valve H, which will thus be opened sufficiently to make the engine revolve in the direction corresponding to the revolution of the screw. The rudder-shaft K, being driven by the pinion T on the engine crank-shaft S, will also revolve, and with it the nut J, the rotation being in the same direction as that of the screw I. As the screw will continue to travel endways until the nut and the screw both revolve at exactly the same speed, the stop-valve H will continue to open until the motion of the engine corresponds exactly with the motion of the telegraph shaft C from the bridge: that is, until the engine is moving at the speed required. This self-acting adjustment, which has taken some time to describe, is all done at the very moment that the bridge steering-wheel is moved, in consequence of the automatic action of the differential screw; and the motion of the rudder wheels E E at the stern is sensibly simultaneous with that of the wheel D at the bridge. The same action of course takes place on occasion of any change in the rate of motion, the position of the stop-valve being immediately altered to give the corresponding speed of engine; and when the motion of the steering-wheel at the bridge is discontinued, the valve closes just so far as to maintain the engine at rest.

If there is a strain on the rudder in the position in which it is required to be held, the stop-valve does not shut altogether, but only so far as to maintain just such a pressure on the pistons as will exactly counterbalance the pressure on the rudder. In this condition the engine becomes simply an automatic steam break, requiring no attention from the steersman. If the strain alternates from one side of the rudder to the other, the stop-valve immediately reverses its position so as to bring the steam pressure on the opposite side of the pistons, and thus restores the equilibrium. However suddenly or violently this alternation of strain may take place, there is no danger to any of the men, as the differential screw is constantly ready for work, and its action is far more perfect and trustworthy than the labour of any number of men at the wheels. Manual labour indeed is not at all adapted for this kind of effort; for while the men are pushing the wheel in one direction it may suddenly happen that the resistance changes its direction, and the men are thrown over the wheels, partly by the force they themselves are exerting, which they cannot change quickly enough to the contrary direction. But in the steam steering gear the differential screw is a perfect automaton, changing the action of the valve not after the change of the strain on the rudder, but by that change itself and simultaneously with it.

The differential screw I has a free range of two turns, equal to 2¼ inches of longitudinal travel, supposing the nut were held stationary; and there is a stop clutch on each end of the screw limiting its travel, as shown in Figs. 6 and 10. In the steam steering however the rudder follows so closely the movements of the steering wheel at the bridge, that in all ordinary weather the screw does not run more than one quarter of a turn in advance of the nut; in which case the steering wheels at the stern are one quarter of a turn behind the wheel at the bridge. Supposing the wheels to be then revolving at a speed equivalent to 30 or 40 turns per minute, the steering wheel at the bridge will be about half a second in point of time before the wheels at the stern; and as the advance of the differential screw is less for a lower speed, the result will be about the same in respect of time, namely that the stern wheels will be only about half a second behind the bridge wheel, whether the latter is being turned rapidly or slowly.

The Rudder Indicator and Steering Dial at the stern, shown in Figs. 6 and 7, Plate 101, is adapted to steering either by men alone or with the engine. This indicator is worked by the same steering-wheel D at the bridge, and is indeed always working, whether steam power or manual labour is employed; so that the engine can be thrown out of gear and men put to the stern wheels without making any change at the bridge or without the steersman at the bridge being even aware that a change has been made.

The two toothed sectors M and P, Fig. 6, each turning independently on the same centre, are actuated by worms on the shafts N and O respectively, the shaft N being geared by the spur wheel L to the differential screw I, and the shaft O by an equal spur wheel to the nut J. The worms working into the arcs are made with contrary threads, the one right-handed and the other left-handed, in order that by the movement of the two shafts N and O in the same direction the two sectors may also be turned in the same direction. The sector P carries an index cast in one piece with it, and being actuated from the rudder-shaft K through the differential nut J it indicates upon a graduated fixed dial the actual position of the rudder, and is therefore called the rudder indicator. The shaft N being united by a coupling V with the telegraph shaft C from the bridge, the movement of the sector M is directly controlled by the steering-wheel D at the bridge; this sector also carries an index, called the director, but this index is jointed to both the sectors M and P; and the distance between the centres of the two joints being short as compared with the length of the index, any difference in the motions of the two toothed sectors is shown magnified at the extremity of this jointed index arm, and the men at the stern steering-wheels are thereby directed to put the wheels over to the side towards which this index points. This jointed index travels over a graduated scale formed on the arm of the rudder indicator P; and by its position shows how much the wheel at the bridge is in advance of the stern steering-wheels, and thus indicates that the steering-wheels should be moved faster or slower in order to keep pace with the movement of the wheel at the bridge.

By this arrangement it will be seen that the differential movements of the screw I and nut J relatively to each other produce similar differential movements of the two index arms M and P relatively to each other, the difference being magnified by the director upon the graduated scale formed on the rudder indicator. When the wheel at the bridge is moved in either direction, the director advances in the same direction beyond the centre of the rudder indicator, and remains in advance until the actual position of the rudder corresponds with the required position; as soon as this is the case, the bridge index, the director, and the rudder indicator, all point to the same position for the rudder.

In addition to this visible intimation to the steersman, there is also a bell W with hammers fixed on the upper end of the differential screw I, as shown in Figs. 9 and 10, Plate 103. A pin X is fixed in the nut J so as to engage with the hammer levers, in order to give signals of warning, and if required to strike repeatedly for urgency. The signals are, one stroke of the bell on leaving the centre in either direction, and one stroke when the required position is reached; and these signals are given by the ordinary movement of the steering-wheel, without requiring any separate action for the purpose. Should the steering-wheels be turned too far, the bell will strike again, and the director finger will point in the contrary direction; and it is the duty of the men at the wheels to maintain the director midway between the two strokes of the bell. In the actual working of the apparatus on the Great Eastern the indicator and bell fulfilled their purpose admirably; but as the automatic steam steering also answered completely, these additional appliances were not really required, and unless for some special reason they would not be made again.

The steering wheel D at the bridge, shown in Figs. 3 and 4, Plate 99, is provided with stops corresponding to the two extreme positions of the rudder, by means of the traversing stop-nut Q, working on a screw cut upon the shaft of the hand-wheel D. This nut is prevented from turning with the shaft by sliding along a fixed guide-plate below, and carries projecting stops which catch at either end of its traverse against stop clutches fixed on the shaft, thereby preventing the further rotation of the shaft when the extreme position has been attained in either direction. The hand steering-wheel D is itself connected to the shaft by means of a safety clutch Y, formed of two pieces engaging with one another by inclined driving faces. The after half of the clutch, on which the hand-wheel D is fixed, turns loose on the shaft, but without any end movement; while the forward half sliding by a feather on the shaft is held up in gear by the spiral spring R. The pressure of this spring is adjusted for holding the inclined driving faces of the clutch Y in gear, and thereby enabling the hand-wheel D to turn the shaft, so long as the traversing stop-nut Q leaves the shaft free to turn; but when either of the stop clutches catches against the nut Q, the safety clutch Y gives way under any force turning the hand-wheel D further in the same direction, by the inclined driving faces of the clutch slipping past each other, forcing the clutch out of gear. This slipping of the safety clutch Y does not derange any of the pointers, and the clutch requires no throwing in again, as it comes into gear itself at each half turn of the hand-wheel D; and the irregularity thus produced in the resistance of the hand-wheel indicates at once to the steersman that the wheel is not driving the shafting. This form of safety clutch is preferable to the common friction clutch, which can never be regulated to a given pressure as this is; and to make a friction clutch slip requires at least as much force as before it slips, so that there is no direct intimation of the slipping.

The shafting C, Figs. 1 and 2, communicating from the hand-wheel D at the bridge to the steering gear at the stern, is formed for the sake of lightness of solid-drawn iron tubes, $1\frac{1}{4}$ inch external diameter and $\frac{1}{4}$ inch thick, turned down at the bearings to $1\frac{3}{16}$ inch diameter, and running in cast-iron bearings bored out to $1\frac{1}{4}$ inch diameter. The total length of this shafting is 410 feet, and there are about 50 pedestals to carry it, and 5 pairs of mitre wheels, in addition to the rest of the working gearing at the bridge and at the stern. The shafting has not been oiled since its erection in March of this year, and it is still as easily worked as when first erected; the whole line of shafting can be turned easily even with the power of one finger at the bridge wheel D. The fixing of the pedestals in the ship was very carefully performed, in order to ensure great accuracy in lining off the shafting; and to this in a great measure is the ease of working to be ascribed. The shafting lies in one of the box beams or tubes, formed in the upper deck, and is carried in a straight line through the interior of it; the twist upon the whole shafting, including the play in the teeth of the pinions, is about one eighth of a turn. In one modification of this system of steering, the same operations are accomplished with a rope connection instead of the shafting; and in another arrangement the connection is made by water pipes, not transmitting steering power, but simply working the differential screw by water pressure: the shafting however is considered to be the best adapted to the work. This system of steering is peculiarly well adapted for ships of war, as the steering can be controlled from a protected look-out forwards, or from any other position in the ship, while the steering engine can be placed below the water line.

In order to prevent accumulation of water in the cylinders of the steam engine when not in motion, the steam passages are formed to droop from the lowest part of the cylinders towards the exhaust, as shown in the transverse section, Fig. 12, Plate 105. The steam pipe to the steering engine being 250 feet long from its connection with the main steam pipe, a self-acting steam trap is provided to allow the discharge of any water that may condense in the pipe. There are no escape cocks or escape valves on the engine, but not the slightest hesitation has ever been found in starting the engine after standing for any length of time without motion. This getting rid of all condensed water was made a first consideration in the arrangement; and the expedients adopted for the purpose have proved thoroughly satisfactory.

The engine shaft S, Figs. 5, 6, and 8, has a disc crank on each end, and the pinion T on this shaft drives a spur wheel on the rudder-shaft K, the proportion of the gear being 1 to 5. The number of turns of the rudder-shaft K is 7 turns either way from the midships position of the rudder, or 14 altogether; so that to put the rudder over from midships to hard-a-port or hard-a-starboard requires 35 revolutions of the engine. The cylinders are 10 inches diameter and 12 inches stroke, as shown in Figs. 11 and 12; the steam is supplied from the main boilers of the ship, and the size of the engine is sufficient for steering when the steam pressure is only 7 or 8 lbs. per square inch, but the pressure is intended usually to be 20 lbs.

The driving pinion T on the engine shaft S is fitted on feathers on the shaft, Fig. 6, and can be slided out of gear even while the engine is running, by means of a forked arm working upon the screwed shaft U turned by a handwheel, Fig. 8. In the case of the Great Eastern the steering engine was specially fitted to act as a steam windlass with two grooved winding-drums, in order to turn the engine to some account when not steering. For this purpose the driving pinion T, when not in gear with the rudder-shaft K, is in gear with two spur wheels on the shafts of the winding drums, the proportion of the gearing being 1 to 4; and a hand starting-lever on the valve shaft is then used for working the steam stop-valve H, instead of the differential gear. This winding gear was added to the steering engine at the request of Captain Anderson, but it is omitted in the drawings, as not forming part of the steering action. The details of the engine itself are so simple and durable that there is no chance of its getting out of order; and none of the joints have ever been broken since it left the makers' works. All the parts are made of extra strength, and the wear of any of them will not prevent the working of the engine.

The last voyage of the Great Eastern to New York was a very stormy one, and afforded an excellent opportunity for trying the efficiency of the steam steering engine. Originally Captain Anderson intended not to use the engine for steering except when out at sea, considering that the ship could not be safely trusted to any steam steering engine when within sight of land; but when the apparatus was completed and its sufficiency became more apparent, the steering of the ship from her moorings in the Mersey was committed to the engine, although the precaution was taken of having men standing by ready to take the wheels if needed. The action was from the first quite satisfactory, and as the mode of steering is just the same as steering by hand, no time was required for training the men to work it.

When approaching Cape Race at the end of the voyage, the sea being very rough, the men were ordered to take the wheels and the steam engine was disconnected. This was done, not because there was any defect in the steam steering, but because a storm was coming on and the vessel was on a dangerous coast, and there had been no experience of the steam steering in a storm. The men had been however only about a quarter of an hour at the wheels, when it was evident the vessel was not steered so well as before, and the men were already quite exhausted. The steam steering engine was therefore again connected, and it was used all through the storm, which was so severe that it necessitated turning the ship about for some time, after the forward bulwarks had been carried away, killing one man and injuring others. Turning so large a ship as the Great Eastern in such a sea would have been almost impossible with steering by hand; but it made no difference to the steam steering engine, and even when the ship got into the trough of the sea the wheel at the bridge was quite passive in the hand of the steersman, and could be moved as easily as in a calm.

The result was so satisfactory that Captain Anderson wrote from New York, "the steam steering gear seems perfection." The experience of its working on the return voyage was equally satisfactory, and Captain Anderson has expressed his high opinion of its value, especially for large steamers.

Mr. C. W. **Siemens** observed that the present paper was the first they had had upon a subject which he thought was a very important one; for to see a large number of men at the helm of a big ship, trying to bear her round, certainly showed great imperfection in the present mechanical arrangements for steering. The apparatus now described as applied to the steering of the Great Eastern gave evidence of a great deal of thought; and the details of the arrangement for starting the steering engine and making it obey signals given from a distant part of the ship were highly ingenious, and the results of the working in practice showed that all the requirements of the case had been duly considered beforehand. He enquired whether any difficulty had ever been experienced in starting the engine after it had been standing for a time, owing to accumulation of water in the cylinders; and whether a difficulty did not arise from the same cause whenever the rudder had to be held by the engine for any length of time in the same position; and he asked what provision was made for getting rid of water in the steam cylinders.

Another question that had occurred to him, though somewhat beyond the immediate subject of the paper, was whether the steering engine during the time that it was standing might not be made serviceable for aiding in the propulsion of the ship by means of a Ruthven reaction propeller, discharging a jet of water from the stern in the opposite direction to the ship's motion. He did not advocate such a mode of propulsion in substitution for the screw and paddles; but he thought it might be advantageously applied in conjunction with these, for utilising a moderate auxiliary power from a separate engine like that employed for the steering gear, which was not required to be constantly at work for steering. The stream of water projected backwards from the stern might either be discharged in a line parallel to the keel of the vessel, or by means of deflectors it might readily be diverted to either side for changing the ship's course. Such an arrangement he thought would have several advantages over any plan of steering by a rudder, because the action of a rudder depended upon the onward motion of the ship, and without onward motion a rudder could produce no effect; whereas by a jet of water issuing laterally from the stern the ship could be steered round while she was not moving forwards or moving very slowly, which in some circumstances was an important consideration. In managing a ship for the purpose of picking up submarine telegraph cables he had himself found very great difficulty in turning the ship round by means of the rudder, while obliged to remain stationary upon the same spot for the performance of the necessary operations. Moreover if such a plan of steering by a water jet were thoroughly carried out, the rudder, which was the most vulnerable portion of a ship, might be dispensed with.

Mr. **Gray** explained that all liability of inconvenience from accumulation of water in the horizontal steam cylinders of the steering engine was obviated by making the steam passages droop from the lowest part of the cylinders towards the exhaust outlet. A steam trap was also provided upon the steam pipe, close to the engine, for the separation of any water condensing in the pipe; and in this way he had endeavoured to arrange, firstly that no water should be carried into the cylinders with the steam, and secondly that in the event of condensation in the cylinders themselves the engine should be equally capable of working, even if in an extreme case the cylinders became completely full of water. This arrangement had proved quite successful, and the engine could in fact be worked as readily by water pressure as by steam.

Mr. F. J. **Bramwell** presumed that the slide valves of the steam cylinders were made with very little lap, so that an indicator diagram taken from the cylinder would show a square figure, without the corners being rounded off at all.

Mr. **Gray** replied that that was the case, the slide valves having only just so much lap as was necessary to keep them steam-tight. For ensuring the greatest facility for escape of water from the cylinders, a clearance of ¾ inch of stroke was left at each end of the cylinder, having abundant area of opening into the port when the piston was at the end of the stroke. With these arrangements he had felt so confident of no difficulty being experienced from water in the cylinders, that he had not made any provision of escape valves or blow-off cocks on the cylinders; and the results of working had shown that no such provision was requisite, as the engine started at all times with perfect readiness, however long it might have been standing with steam on.

In reference to the suggestion of employing a steering engine acting by means of a Ruthven propeller and also aiding in the propulsion of a ship, he thought it was far better for the propelling engines to be available for steering as at present by means of the ordinary rudder; for with the rudder turned at an angle to the ship, the propelling power of the screw or paddles became effective in altering the ship's course. Judging from the trials of the Ruthven reaction propeller in the Waterwitch, he believed the whole engine power of that vessel would be altogether inadequate for steering the Great Eastern, if the steering were effected by means of that propeller instead of by the present rudder. In contriving the steam steering gear for the Great Eastern, much unnecessary difficulty had been encountered from the stringent stipulations laid down in that particular instance; but now that the success of the arrangements had been so satisfactorily demonstrated by actual trial, there would be no occasion to complicate the plan in any future case by providing for contingencies which were found not to occur in practice.

Mr. W. NAYLOR remarked that, as a rudder had no effect in turning a ship except when in motion, an experiment had been tried some years ago with a small auxiliary screw for steering, carried upon an independent shaft at the stern, and so arranged that it could be inclined to a certain extent towards either side. With this plan the vessel was turned round in either direction without any forward motion, turning upon the stem as a pivot; and when propelled by the main screw, there was found to be no difficulty in turning the ship in one direction by means of the auxiliary screw; but the difficulty was to get her round in the opposite direction, on account of the large propeller partly counteracting the influence of the steering screw. A single screw propeller had in fact a constant tendency to turn the ship round towards one side; and this side-way had to be compensated for by inclining the rudder through a corresponding angle towards the opposite side, in order to keep the ship to a straight course. This was not necessary however where there were twin propelling screws, right and left handed, revolving in contrary directions. He had witnessed some interesting experiments in Lowestoft Harbour with screw colliers having only one propeller, where difficult steering to get out of the harbour had been satisfactorily accomplished by reversing the screw at a critical moment, causing the blade of the propeller to drive water against the opposite side of the stern of the vessel, thereby increasing the action of the rudder, and enabling the vessel to be worked out in safety. Another plan proposed for dispensing with the rudder in vessels with a single screw propeller consisted in employing the screw propeller itself for steering the ship, by making the screw shaft with a universal joint, so that the screw could be inclined towards either side to point straight aft where the ship's stern was coming over; but he did not know what had been the success of this plan upon actual trial.

Mr. Gray said he understood a plan of steering by means of the main screw itself had been tried in a vessel of the royal navy; but it was found a very inefficient mode of steering, giving such imperfect control over the course, that on the trial trip the ship came into collision with another vessel.

Mr. E. A. Cowper considered the steam steering machinery was certainly very ingenious, particularly the arrangement of the equilibrium valve for changing the steam passages into exhaust and the exhaust into steam; so that not only was the steam shut off or put on, for stopping or starting the engine, but also the engine was reversed to run in either direction; and all this was effected instantly, by the use of a single stop-valve which was also an equilibrium valve. He quite agreed that a large amount of power was necessary to hold a rudder well over for bringing a vessel round quickly, particularly the long sharp steamers now built, which in respect to the difficulty of turning them were just like long and deep balks of timber in the water. In fact when the rudder was inclined at an angle of about 40° or 45° to the ship's course, corresponding to the average inclination of the blades of a screw propeller, the pressure per square inch upon the rudder was not much less than the mean pressure upon the screw blades; because the lineal velocity of the centre of gravity of each blade in its circle of revolution was not much greater at ordinary speeds than the velocity at which the rudder was dragged through the water by the forward motion of the vessel. He did not see how the same effect in turning the ship could be produced with any less expenditure of power; and therefore it appeared the simplest plan to apply steam power direct to the rudder itself, in a manner such as that described in the paper, instead of attempting to substitute for the rudder any of the other modes of steering that had been alluded to. The remarkable ease with which the large amount of power necessary for working the rudder was brought to bear, by the simple movement of an equilibrium valve, was a point deserving of special notice.

Mr. GRAY observed that the opinion just expressed as to the relative amount of pressure upon the rudder of a vessel and upon the blades of the screw propeller was confirmed by observations made on the actual working of screw steamers; and there was a great deal more total pressure upon the rudder than upon the screw. In any mode of steering by steam power, it was essential that there should be the means of falling back upon hand steering in the event of any accident with the machinery or any deficiency in the supply of steam; just as with regard to the screw and paddle engines, if anything occurred to interfere with their working, it was still possible to have recourse to the sails. In the application of the steam steering gear to the Great Eastern, this condition had been met by so arranging the new apparatus that it did not in any way interfere with the previous hand steering gear, which still remained available for instant use at any moment that might be desired. If the steering however were done by a Ruthven reaction propeller or any other such plan, dispensing with the rudder altogether, there would be no means whatever of steering the vessel if the steam steering gear were ever out of order.

With regard to the steering of steamers in general, he thought that, so long as the present very inadequate arrangement continued of steering by hand labour, the law regulating the navigation of vessels at sea was mistaken in ordering that steamers should in every case keep out of the way of sailing vessels; and he considered the contrary regulation would often be more easily complied with. For in a sailing ship, not only was the speed generally much less, but there were also great facilities for changing the tack readily, by making the wind come to the aid of the rudder for bringing the ship round. In a steamer on the contrary the whole turning effect had to be produced by the rudder alone; and when it was considered that many steamers of 3000 tons now attained a speed of 16 miles an hour, which was nearly the speed of a heavy goods train, it was clear that the power of two or three men at the wheel was quite insufficient for changing the vessel's course in time to avoid a collision in every case. Even a sailing vessel with its sails up had therefore better means of getting out of the way than a steamer. He had been informed by the captain of a steamer that many cases of collision had been occasioned by the circumstance of a sailing ship being suddenly descried in the course of a steamer on a dark night; and so much power was required for getting the rudder over quickly, that all the men on the look-out in the steamer had to run and help at the wheel; and no one being left to look out, a collision was liable to take place. So long therefore as the present law prevailed on this point, he thought that an additional regulation ought also to be made, requiring that every steamer should be provided with sufficient steering power for enabling its course to be changed to a given extent in a stated length of time.

Mr. F. J. Bramwell enquired whether it was found, in steering a steamer with twin screws by reversing one of the screws, that the vessel could be brought round more efficiently than with a rudder. With the twin screws he presumed the effect would be to make the vessel pivot upon its centre, whereas with the rudder it was of course working forwards in a circle.

Mr. Gray replied that the ship's course was found to be changed at least twice as rapidly with an ordinary rudder as by working with twin screws and one reversed. In the latter case, the ship being pivotted upon its centre, both the prow and the stern were being moved round laterally through the water at the same time; but even in a vessel of 300 feet length the two screws could not be placed much more than about 22 feet apart, giving only 11 feet leverage to each screw for turning the ship, against the lateral resistance of the water acting at a leverage of 75 feet.

Mr. C. W. Siemens had no doubt that when a vessel was going at full speed, with room enough to describe a circle of considerable size, the rudder was far more powerful in altering the course than a reaction propeller would be; but the case in which he thought the latter would have a decided advantage was where a ship had to work through a narrow passage and turn a sharp corner, as in entering a dock, when of course it would have so little headway that the rudder would produce very slight effect in bringing it round; under such circumstances a reaction propeller acting obliquely at the stern would be very effective. In regard to the great force necessary for putting a rudder over to either side when the vessel was moving at full speed, another consideration bearing upon this point was that the long straight keel, presenting a large extent of vertical surface to the water on each side, offered a corresponding resistance to any endeavour to change the ship's course in either direction from the straight line; it was itself in fact a powerful rudder trying to keep the ship in a straight course, and required therefore a superior force to alter the course by means of the rudder. On this account he fully concurred in the importance of mechanical steering with adequate power, in place of the present defective hand steering.

With regard to the regulation requiring steamers to keep out of the way of sailing vessels, he did not think it desirable that any alteration should be made, such as had been suggested; because it was only when there was sufficient wind that a sailing vessel could alter its course with greater facility than a steamer, and the loss of way would be a serious inconvenience in the case of a ship tacking against a contrary wind; whereas a steamer, even though less speedily brought round, had always the means of altering its course, without much inconvenience.

Mr. F. J. **Bramwell** enquired whether the rudder of the Great Eastern, to which the new steam steering gear was applied, was a balanced rudder or a common rudder.

Mr. **Gray** replied that it was a common rudder, not balanced; but the control was so easy with the steam steering gear that the rudder could be put about by the pressure of only a finger upon the steering wheel at the bridge. In reference to steering a vessel without headway, it should be observed that the steam steering gear gave the means of accomplishing this with the greatest facility, as it was only necessary to reverse the screw or paddles, and make a few strokes ahead and astern alternately, putting over the rudder at the same time alternately from one side to the other; and with the steam gear this was done even more rapidly than the propelling engines could be reversed.

Mr. F. J. **Bramwell** observed that one important advantage deserving of special notice in the steam steering gear was the fact that, when the rudder was put over into any required position, it was held there by a self-acting steam break, without the necessity for any further attention or exertion on the part of the helmsman. For although the rudder yielded in either direction under an excessive strain produced by the force of the waves, it was brought back again to the original position the instant the strain ceased; and this was accomplished entirely by the self-acting differential screw controlling the steam stop-valve, which he considered a most ingenious and effective contrivance, the steam being thereby admitted to either side of the pistons according to the direction of the pressure upon the rudder.

Mr. **Gray** remarked that, even in the case of backing the ship against a quay, the rudder would give way without injury, and without moving the hand steering wheel at the bridge; but the moment the ship was released, the rudder would spring back to the position in which it was originally placed by the steersman.

Mr. F. J. **Bramwell** thought the whole scheme of the steam steering gear would have seemed at first almost impracticable, considering the number of requirements to be met; but it had now been proved to be eminently practicable, having been carried out with so much success upon the largest ship in the world. He proposed a vote of thanks to Mr. Gray for his paper, which was passed.

The Meeting then terminated.

ATLANTIC TELEGRAPH MACHINERY.

Plate 1.

Fig. 1. *Plan of "Great Eastern" containing Cable and Machinery.*

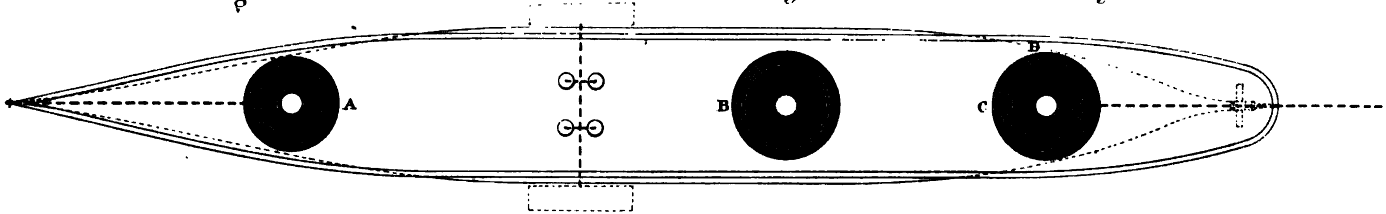


Fig. 2. *Longitudinal Section.*

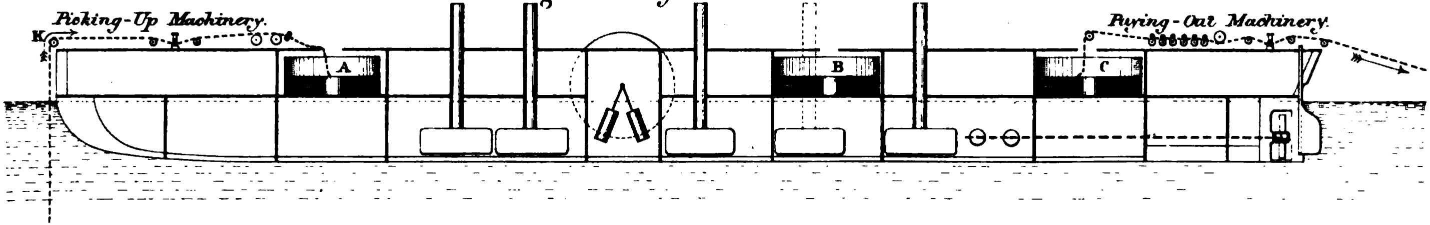
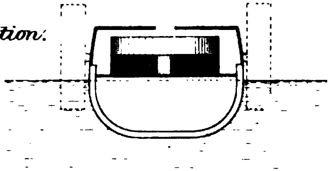


Fig. 3. *Transverse Section.*



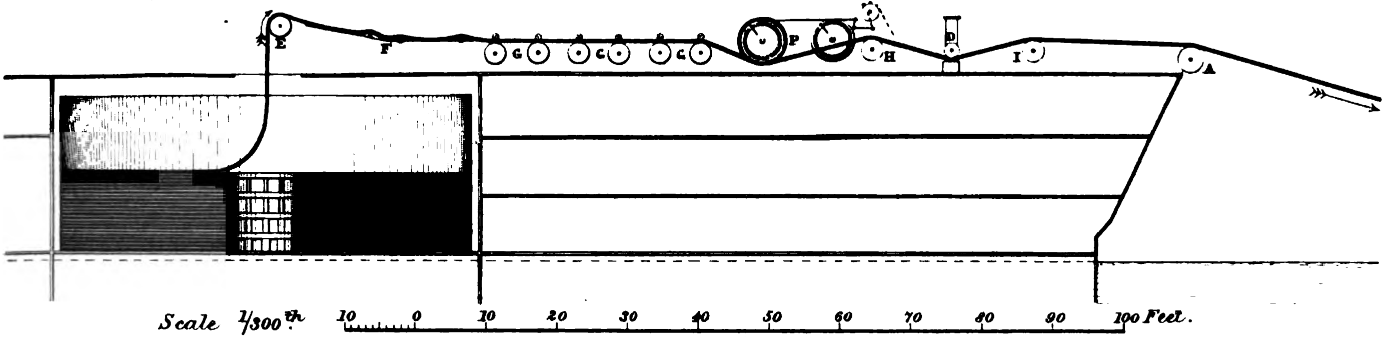
Scale 1/1200th

(Proceedings Inst. M. E. 1867. Page 20.)

ATLANTIC TELEGRAPH MACHINERY.

Plate 2.

Fig. 4. *General arrangement of Paying-Out Machinery at stern of "Great Eastern."*



Scale 1/300th.

Fig. 5. *Theoretical Picking-Up of Cable in single bight.*

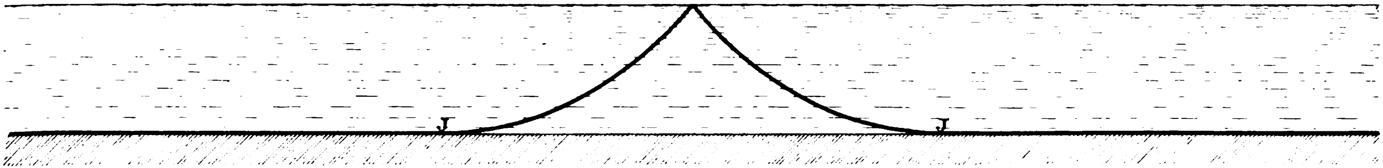
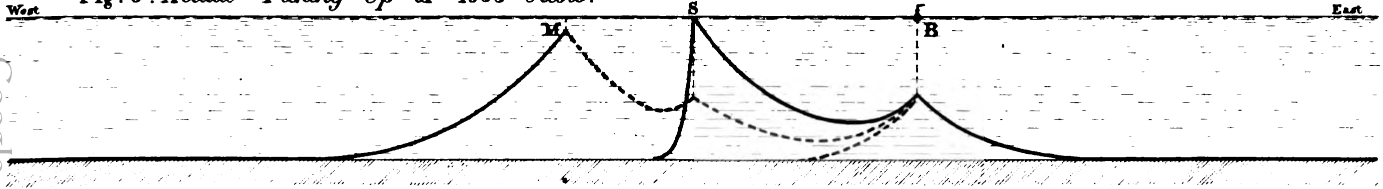


Fig. 6. *Actual Picking-Up of 1865 Cable.*



(Proceedings Inst. M.E. 1867. Page 20.)

Scale 1/3rd inch per knot.

ATLANTIC TELEGRAPH MACHINERY.

Plate 3.

Paying-Out Jockey Gear.

Fig. 7. *Side Elevation.*

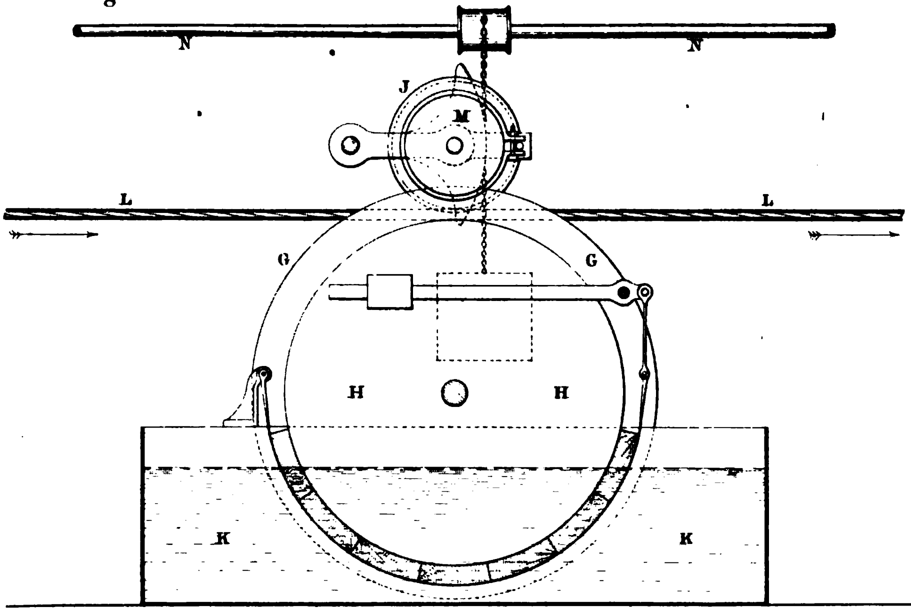
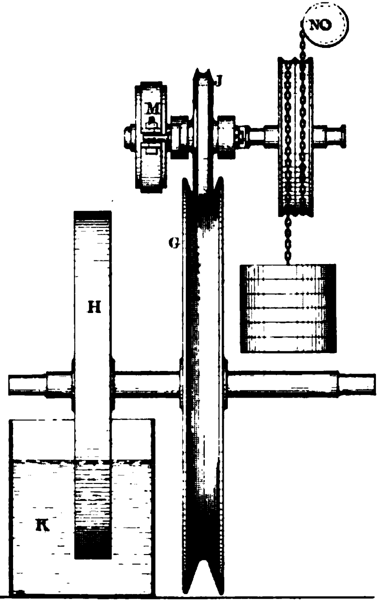


Fig. 8. *End Elevation.*

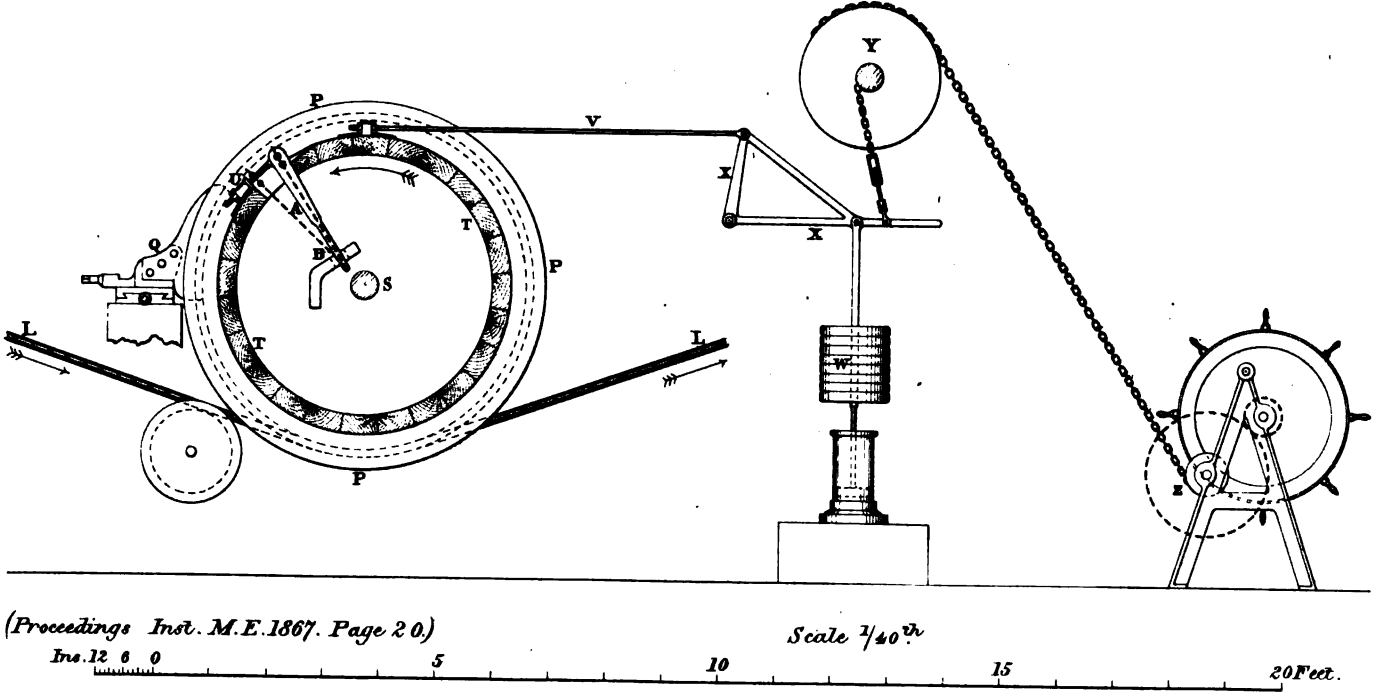


(Proceedings Inst. M. E. 1867. Page 20.) *Scale 1/20th* Ins. 12 6 0 1 2 3 4 5 Feet.

ATLANTIC TELEGRAPH MACHINERY.

Plate 4.

Fig. 9. *Side Elevation of Paying-Out Drum and Friction Breaks.*

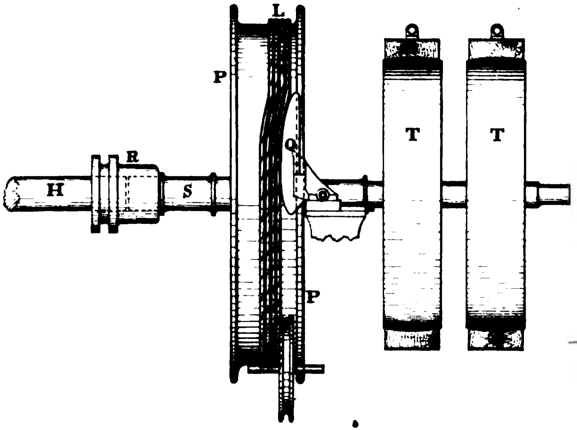


(*Proceedings Inst. M.E. 1867. Page 20.*)

Scale 1/40th.

ATLANTIC TELEGRAPH MACHINERY.

Fig. 10. *End Elevation of Paying-Out Drum and Friction Breaks.*



Paying-Out Dynamometer.

Fig. 11. *End Elevation.*

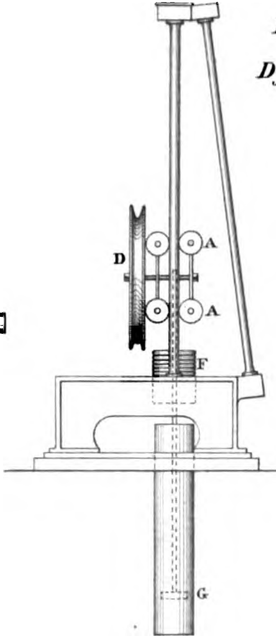
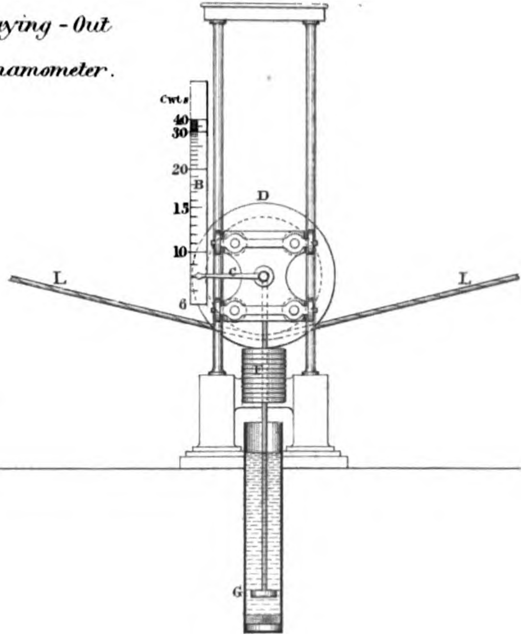


Fig. 12. *Side Elevation.*

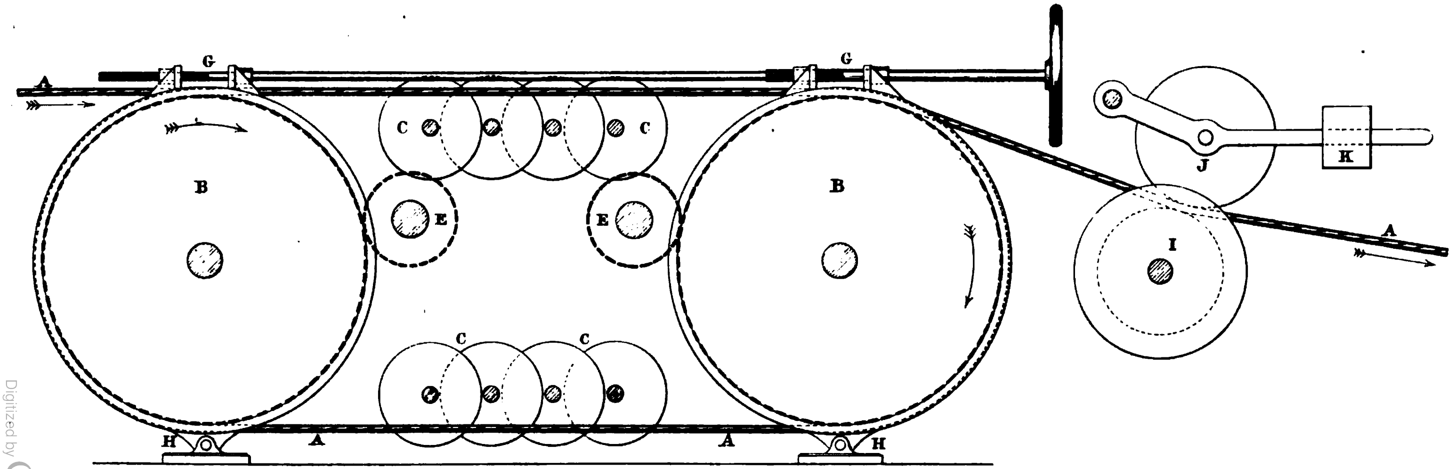


(Proceedings Inst. M. E. 1867. Page 20.)

Scale $1/40^{th}$. *Ins.* 12 6 0 5 10 *Feet.*

ATLANTIC TELEGRAPH MACHINERY.

Fig. 13. *Elevation of Picking - Up Drums.*



Inst. M. E. 1867. Page 20.) *Scale 1/40th* *Ins. 12 6 0 5 10 Feet.*

(Proceedings

ATLANTIC TELEGRAPH MACHINERY.

Fig. 14. *Plan of Picking-Up Drums.*

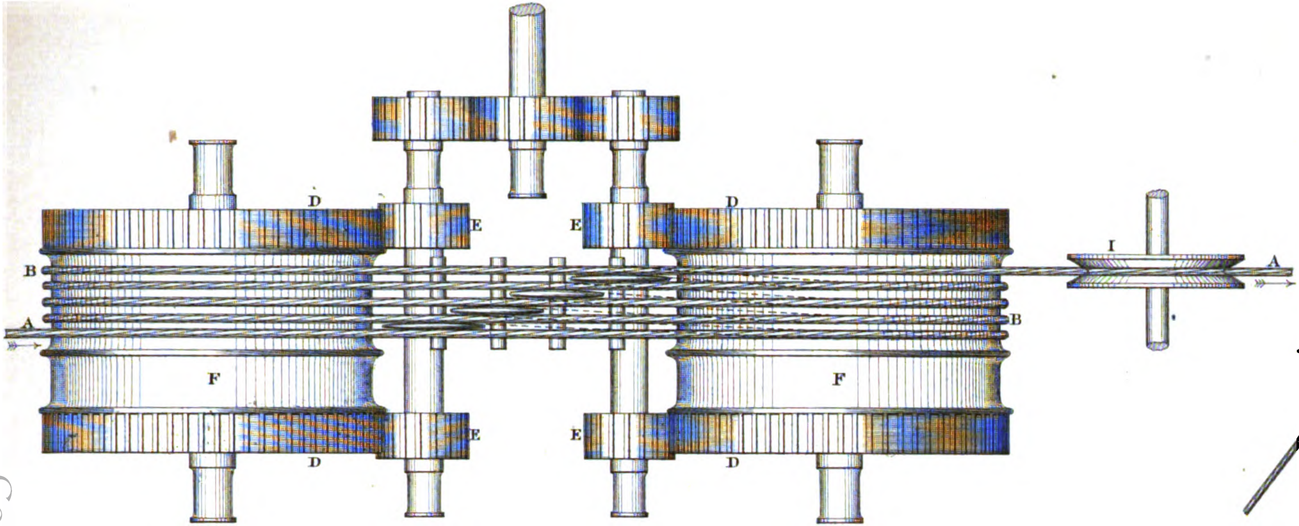
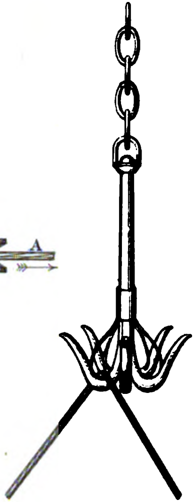


Fig. 15. *Grapnel.*

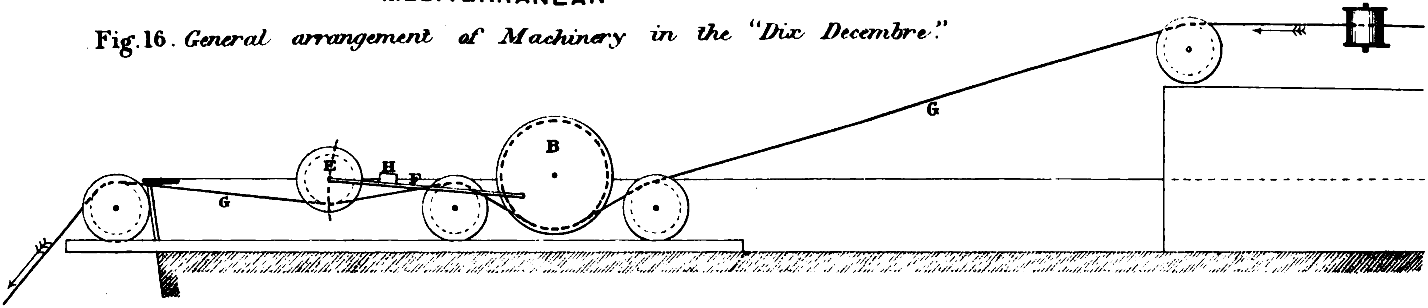


(Proceedings Inst. M. E. 1867. Page 20.) *Scale 1/40th.* *Ins 12 6 0 5 10 Feet.*

MEDITERRANEAN TELEGRAPH MACHINERY.

Plate 8.

Fig. 16. *General arrangement of Machinery in the "Dix Decembre."*



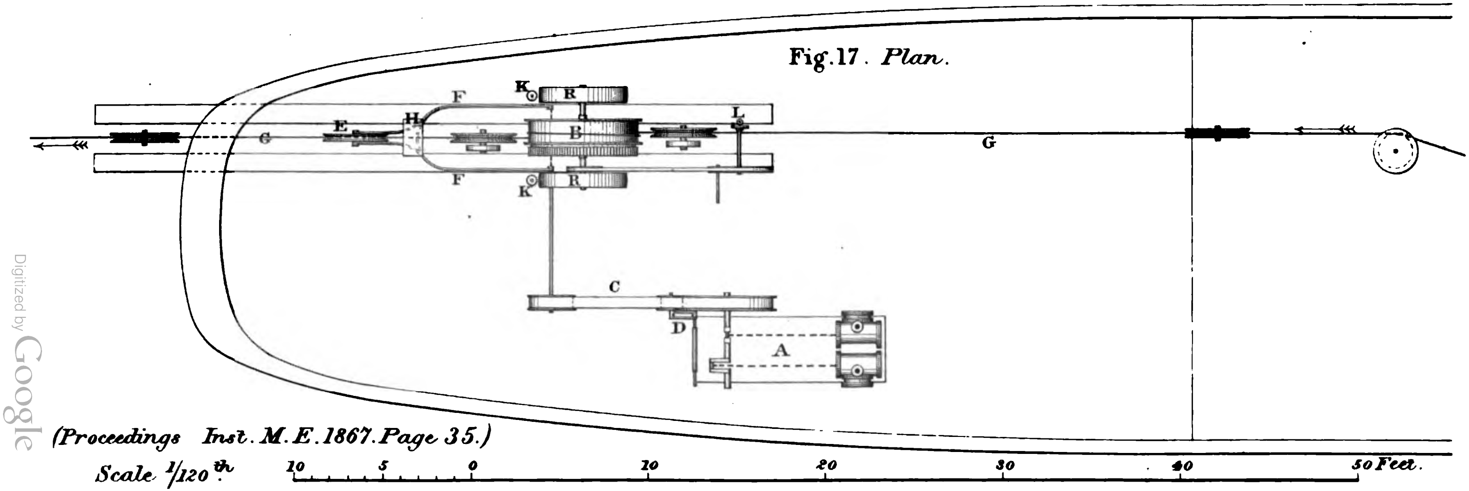


Fig. 17. *Plan.*

(Proceedings Inst. M.E. 1867. Page 35.)

Scale 1/120th.

MEDITERRANEAN TELEGRAPH MACHINERY.

Fig. 18. *Transverse Section through Tank.*
Scale 1/120th.

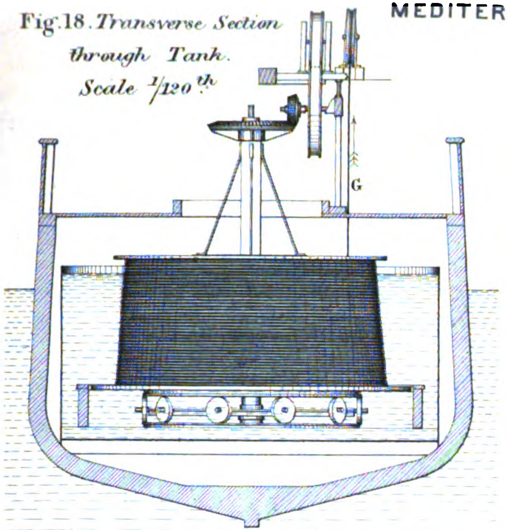


Fig. 19. *Side Elevation of Paying-Out Engine.*
Scale 1/60th.

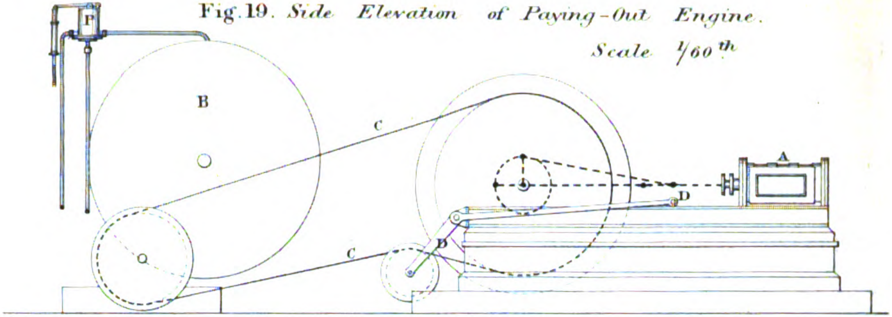
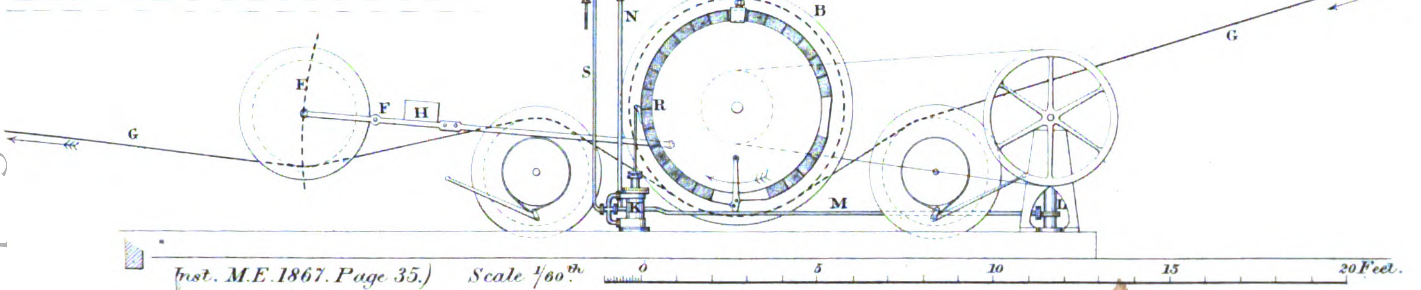


Fig. 20. *Side Elevation of Paying-Out Drum and Dynamometer.*
Scale 1/60th.



(Inst. M.E. 1867. Page 35.) *Scale 1/60th.*

MEDITERRANEAN TELEGRAPH MACHINERY.

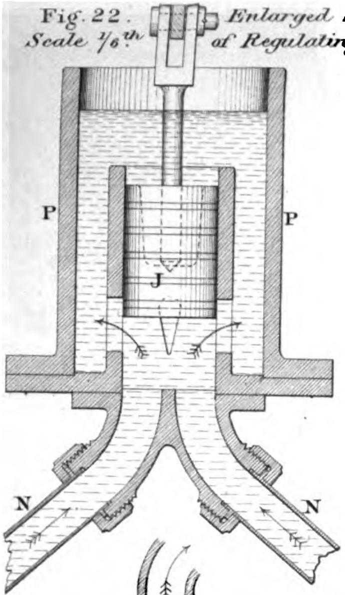


Fig. 22. Enlarged Section of Regulating Valve. Scale 1/6th

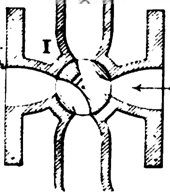


Fig. 23. Section of Four-way Cock. Scale 1/6th.

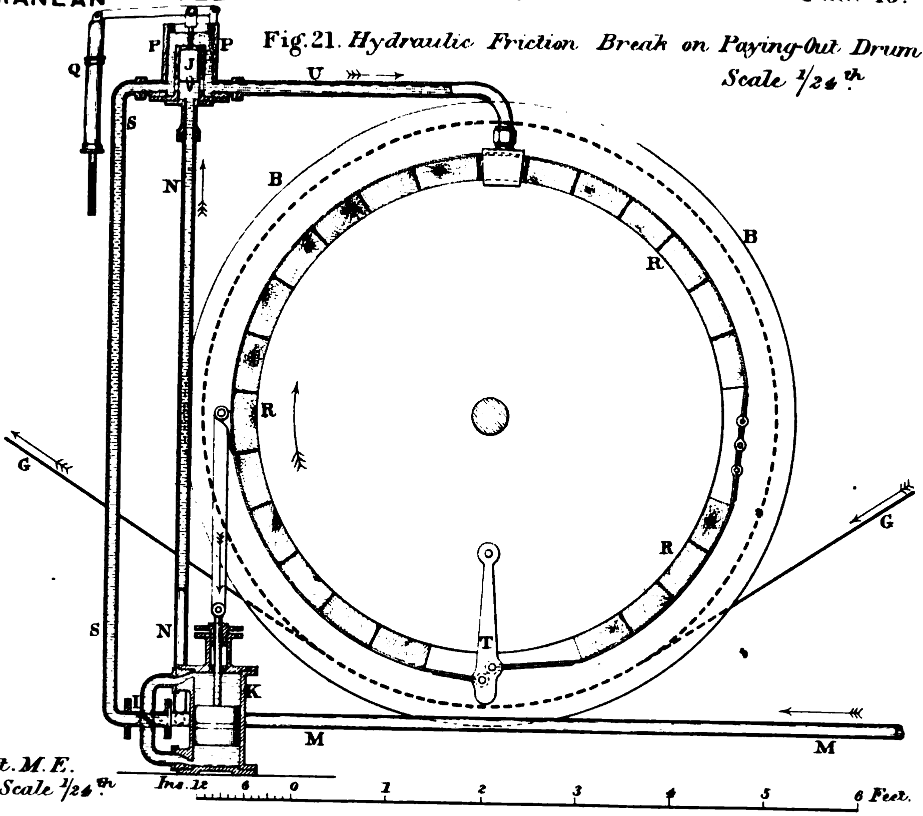


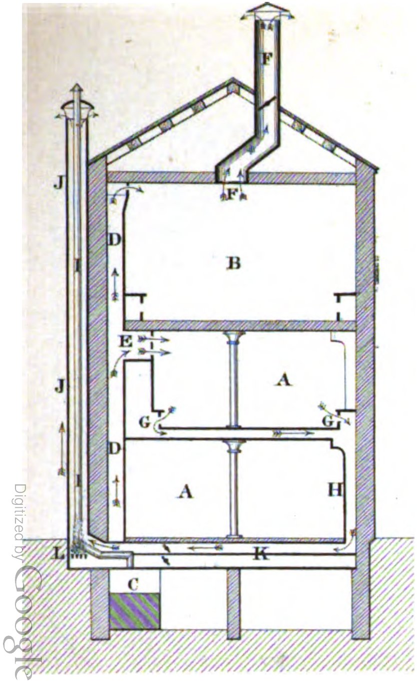
Fig. 21. Hydraulic Friction Break on Paying-Out Drum. Scale 1/24th.

(Proceedings Inst. M.E. 1867. Page 37.) Scale 1/24th.

VENTILATION OF PUBLIC BUILDINGS.

Plate II.

Fig. 1. *Transverse Section.*



Public School, Rue des Petits Hôtels, Paris.

Fig. 2. *Plan of First Floor.*

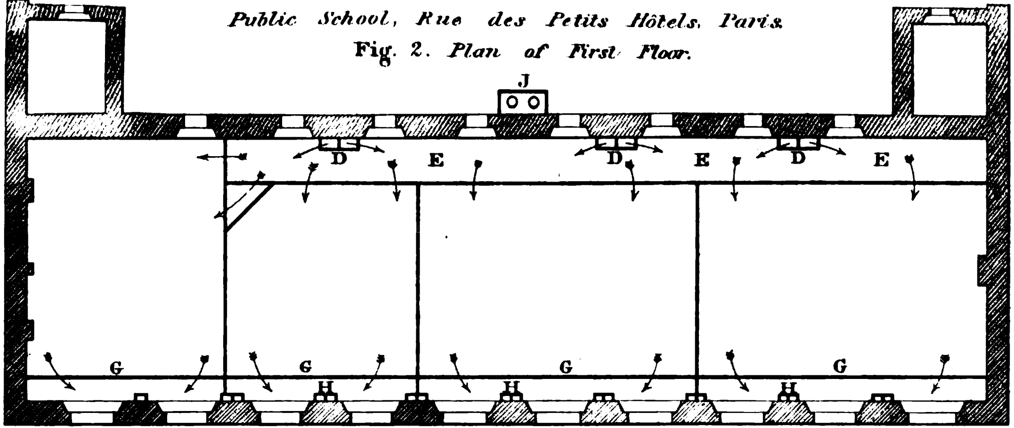
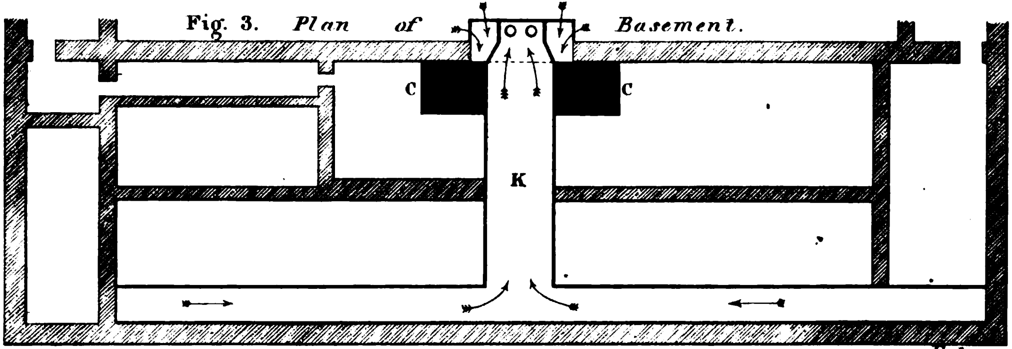


Fig. 3. *Plan of Basement.*



(Proceedings Inst. M. E. 1867. Page 61.) *Scale* $^1/_{240}$ th 10 5 0 10 20 30 40 50 Feet.

Conservatoire Impérial des Arts et Métiers, Paris.

Fig. 4. *Longitudinal Section of Lecture Theatre.*

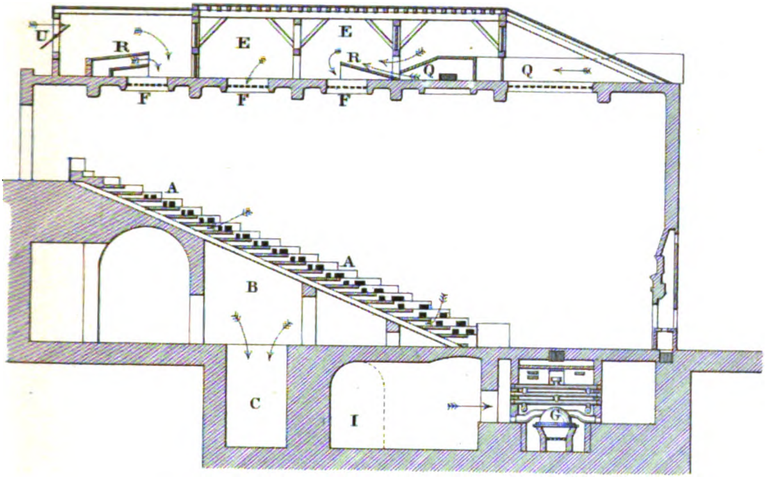
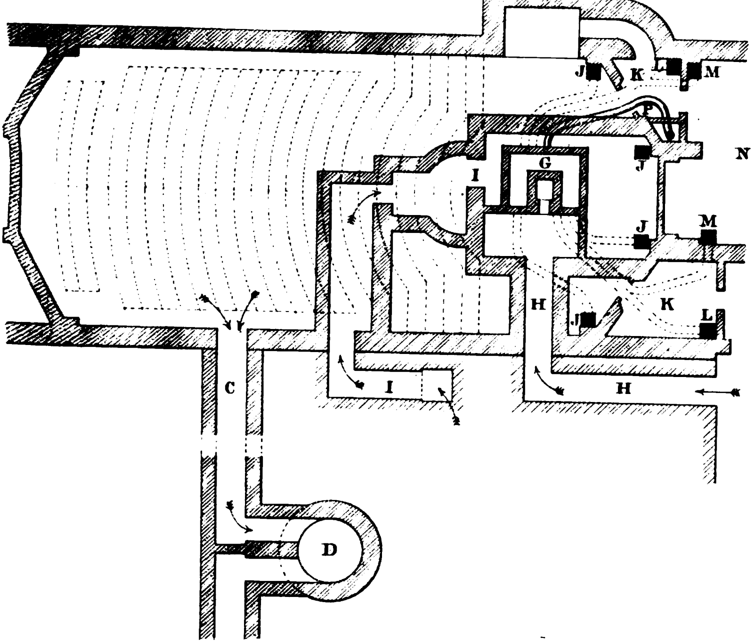


Fig. 5. *Plan of Basement.*



(Proceedings Inst. M. E. 1867. Page 61.) *Scale 1/300th.*

10 5 0 10 20 30 40 50 60 70 80 Feet.

VENTILATION OF PUBLIC BUILDINGS. *Plate 13.*

Conservatoire Impérial des Arts et Métiers, Paris.

Fig. 6. *Plan of Roof of Lecture Theatre.*

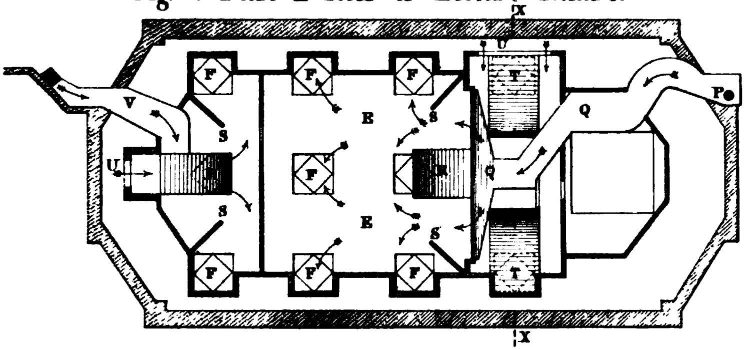
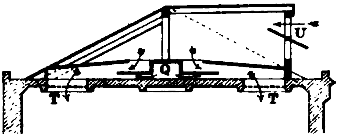
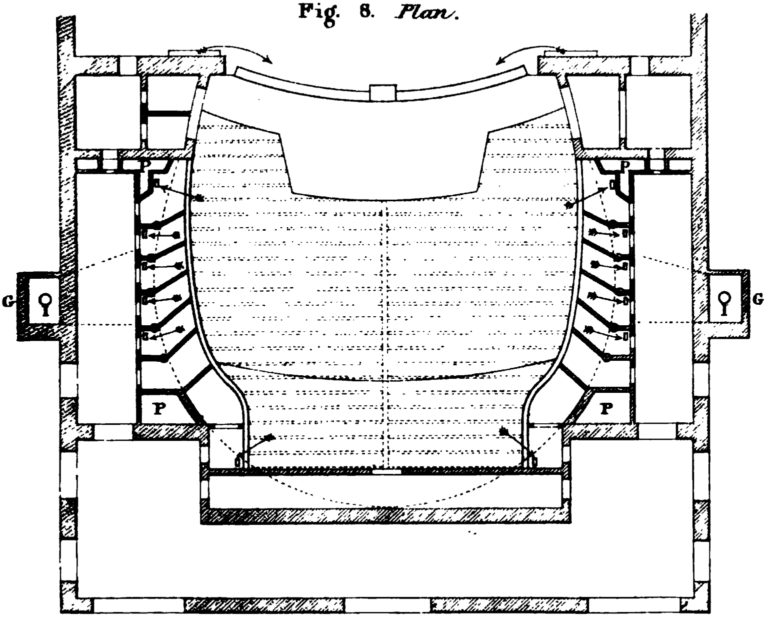


Fig. 7. *Transverse Section at XX.*



Théâtre Lyrique, Paris.

Fig. 8. *Plan.*



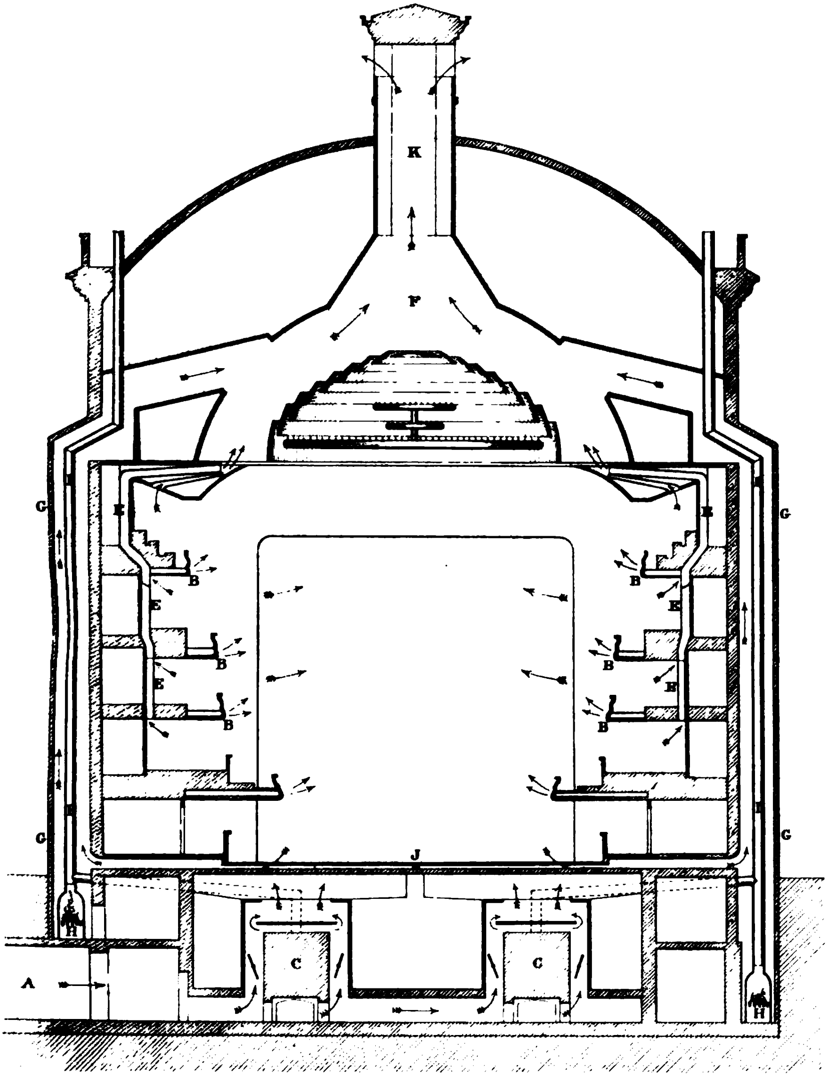
(Proceedings Inst. M.E. 1867. Page 61.) *Scale $1/300^{th}$*

10 5 0 10 20 30 40 50 60 70 80 *Feet.*

VENTILATION OF PUBLIC BUILDINGS. *Plate 14.*

Théâtre Lyrique, Paris.

Fig. 9. *Vertical Section.*



(Proceedings Inst. M. E. 1867. Page 61.) *Scale* $1/300^{th}$

10 5 0 10 20 30 40 50 60 70 80 Feet.

FLOATING DOCKS.

Plate 15.

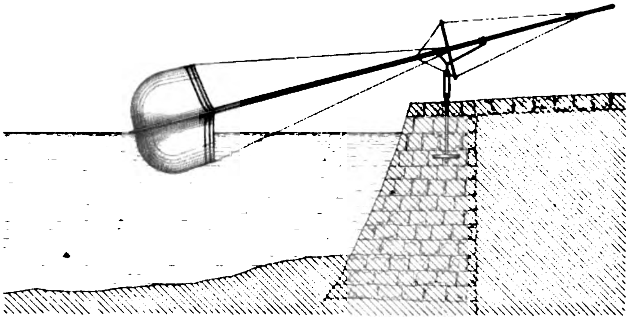


Fig. 1. *Careening alongside a quay.*

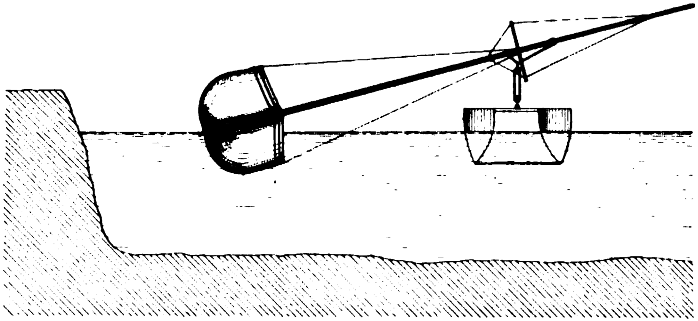


Fig. 2. *Careening independent of land.*

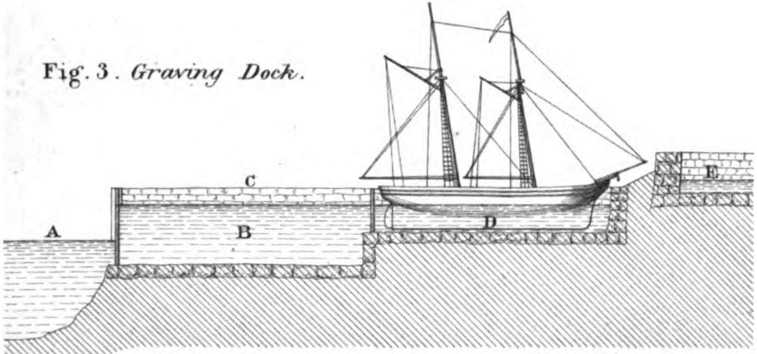


Fig. 3. *Graving Dock.*

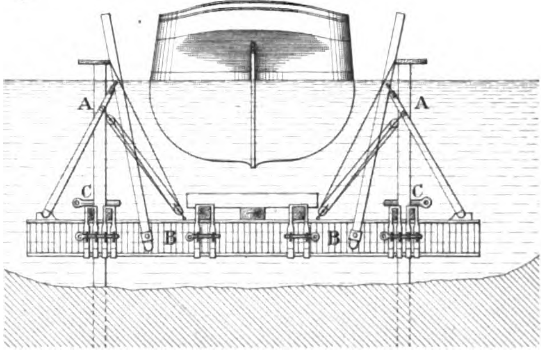


Fig. 4. *Mitchell's Tidal Lift.* 1833.

(Proceedings Inst. M. E. 1867. Page 80.)

Plate 16.

FLOATING DOCKS.

Fig. 5. *Morton's Slip.* 1818.

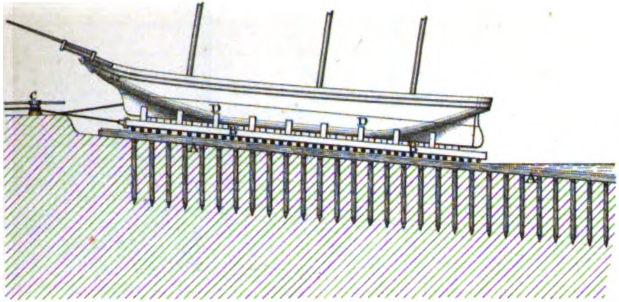


Fig. 7. *Curved Slip, with Dock Gates and Telescopic Cradle.*

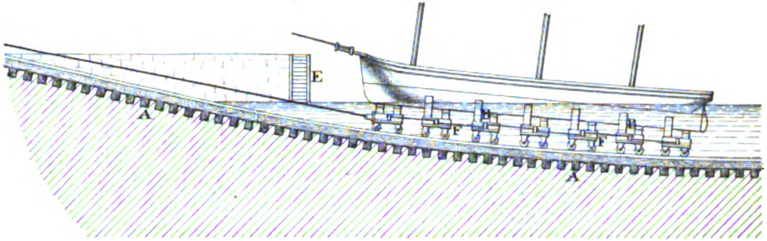


Fig. 6. *Transverse Section of Morton's Slip.*

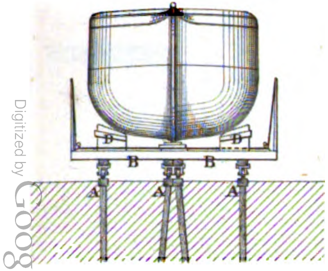


Fig. 8. *Section of Tubular Rail carrying slings.*

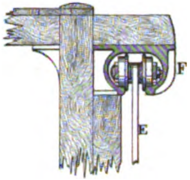
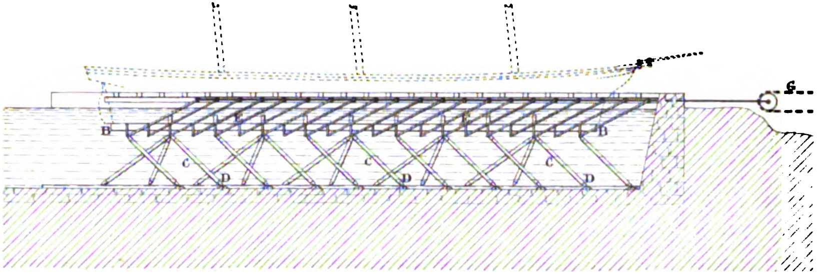


Fig. 9. *Mallet's Parallel-Sling Lift.* 1842.



(Proceedings Inst. M.E. 1867. Page 80)

FLOATING DOCKS.

Fig. 10. *American Screw Lift. 1827.*

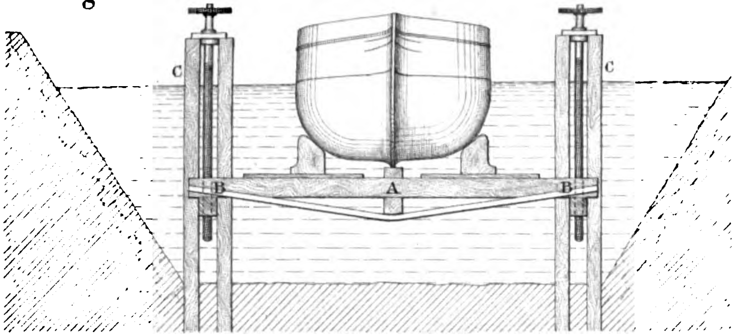


Fig. 11. *American Hydraulic Lift. 1836.*

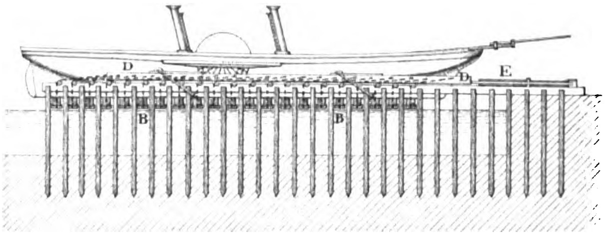


Fig. 12. *Clark's Hydraulic Lift at Victoria Docks, London. 1857.*

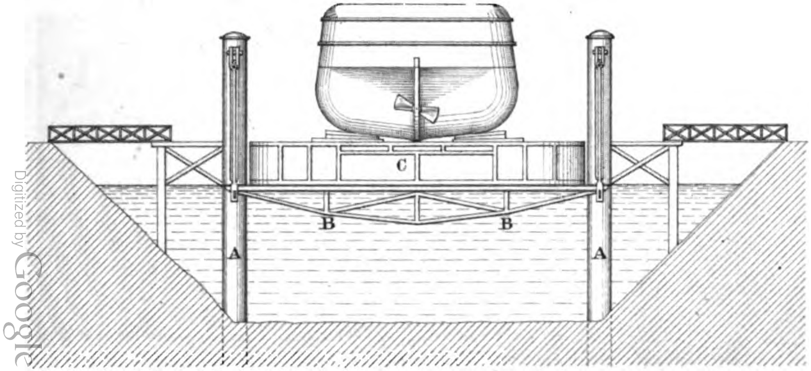
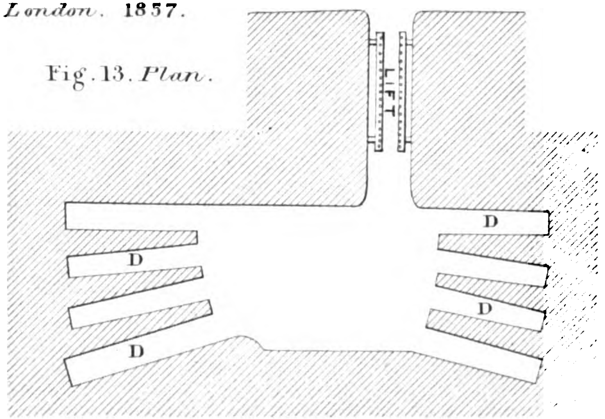


Fig. 13. *Plan.*



(Proceedings Inst. M.E. 1867. Page 80.)

FLOATING DOCKS.

Fig. 14. *Scott's Hydraulic Lift.* 1850.

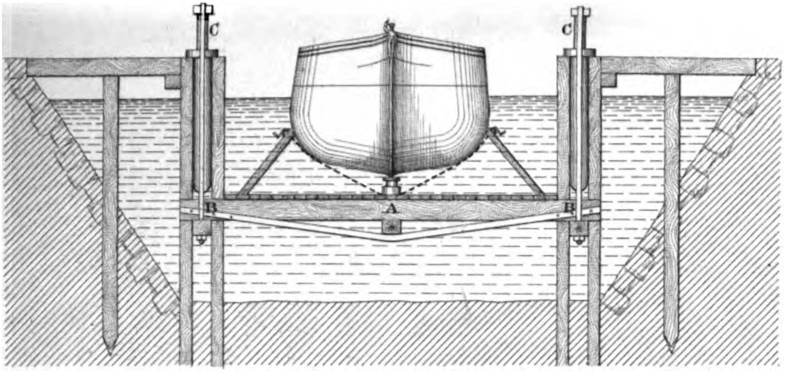
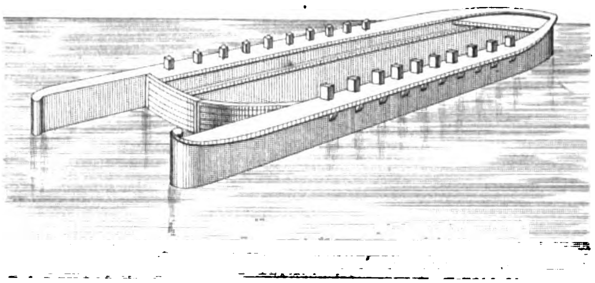


Fig. 15. *Watson's Floating Dock.* 1785.



American Sectional Floating Dock. 1837.

Fig. 16. *End Elevation.*

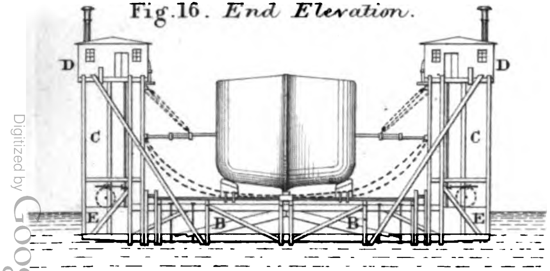
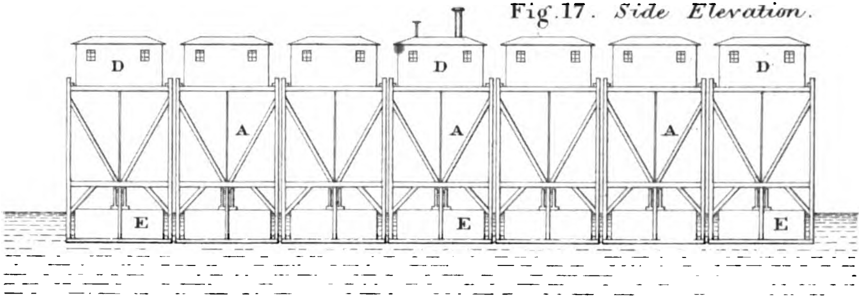


Fig. 17. *Side Elevation.*



(Proceedings Inst. M. E. 1867. Page 80.)

FLOATING DOCKS.

Plate 19.

Fig. 18. *American Balance or Box Floating Dock.* 1839.

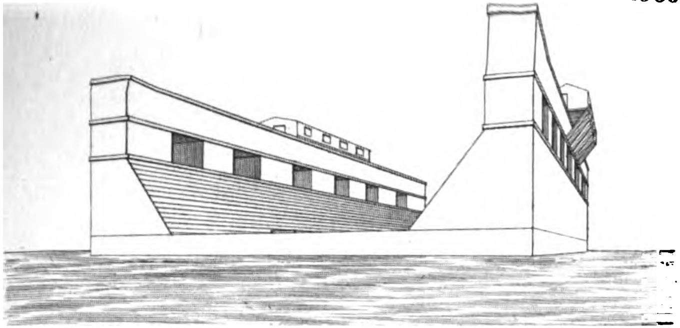
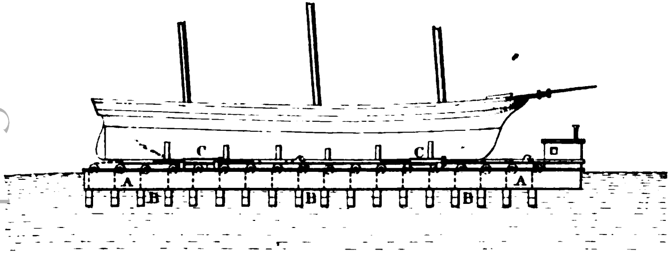


Fig. 19. *Floating Hydraulic Lift for Brazil.* 1859.



(*Proceedings Inst. M.E. 1867. Page 80.*)

Fig. 20.

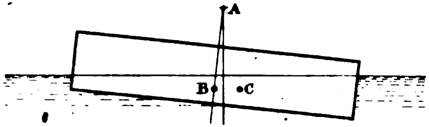


Fig. 21.

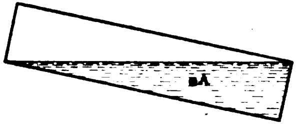


Fig. 22.

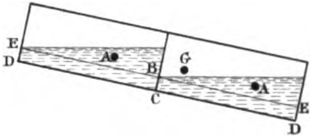
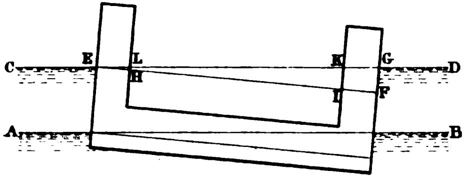
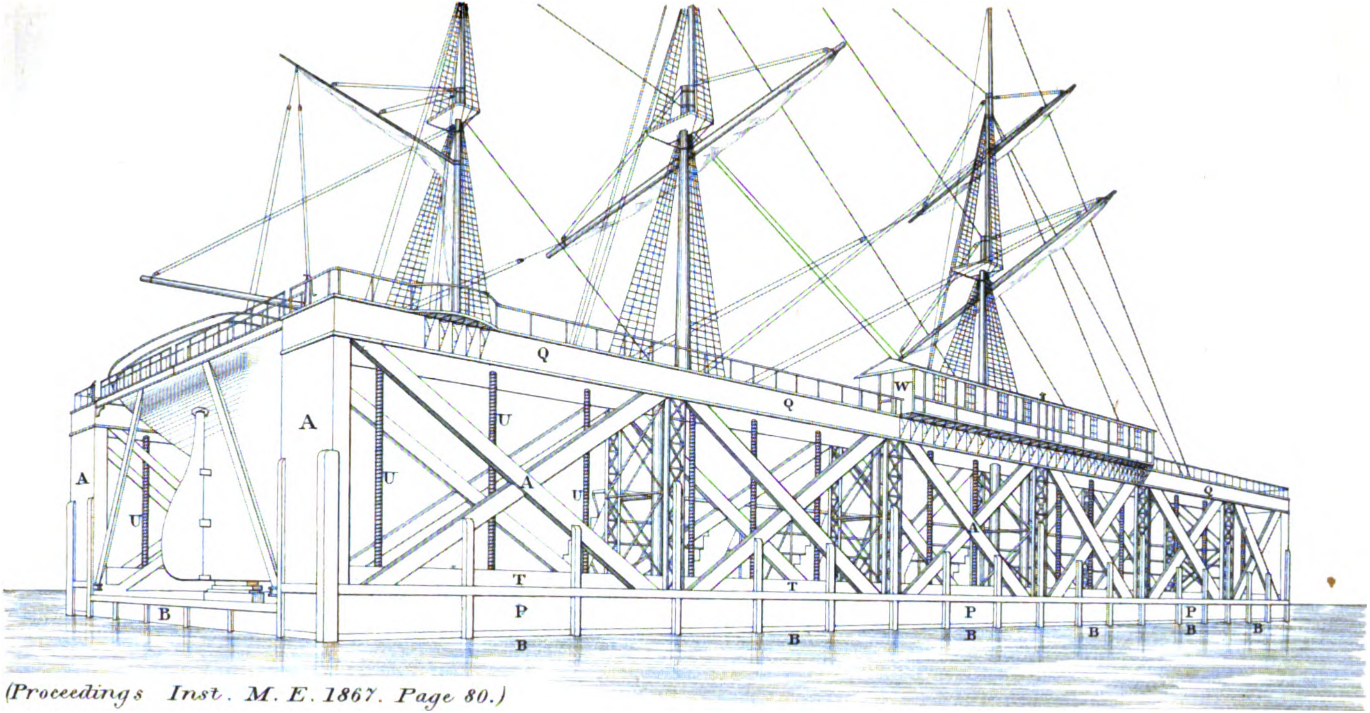


Fig. 23.



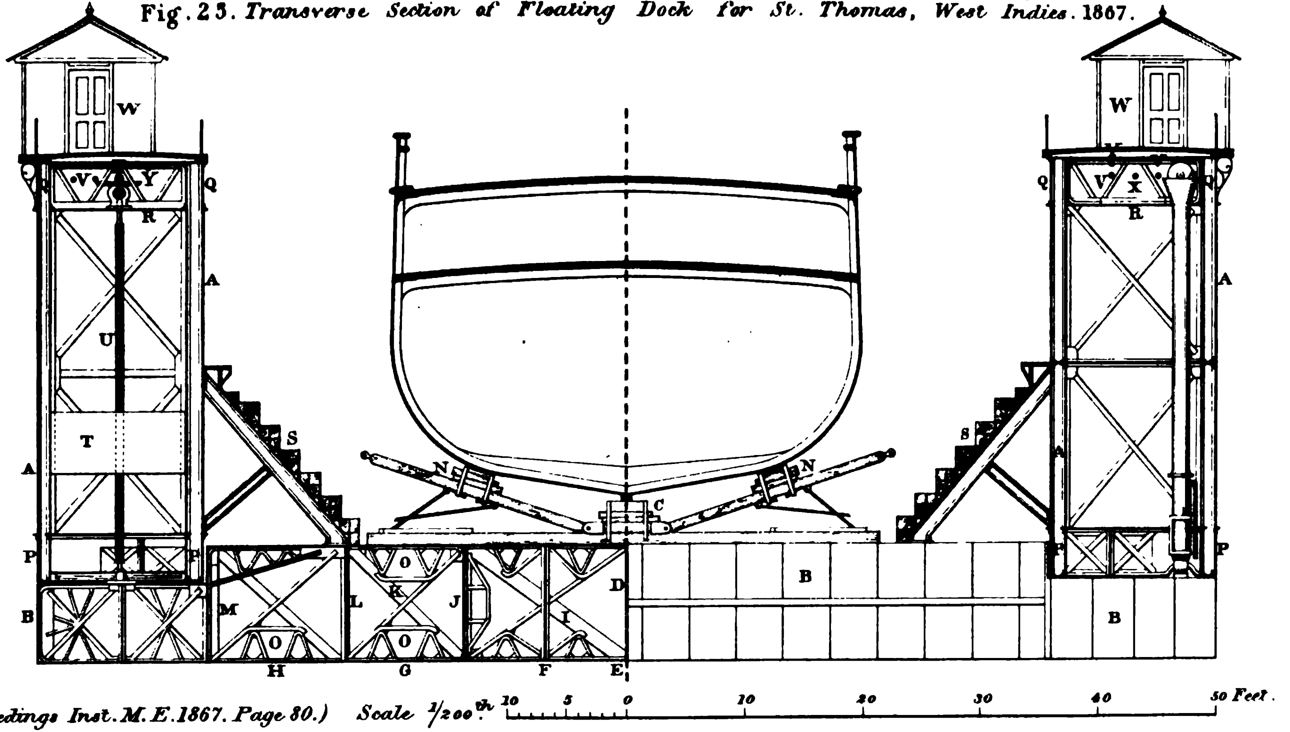
FLOATING DOCKS.

Fig. 24. *Floating Dock for St. Thomas, West Indies. 1867.*



(Proceedings Inst. M. E. 1867. Page 80.)

Fig. 23. *Transverse Section of Floating Dock for St. Thomas, West Indies.* 1867.



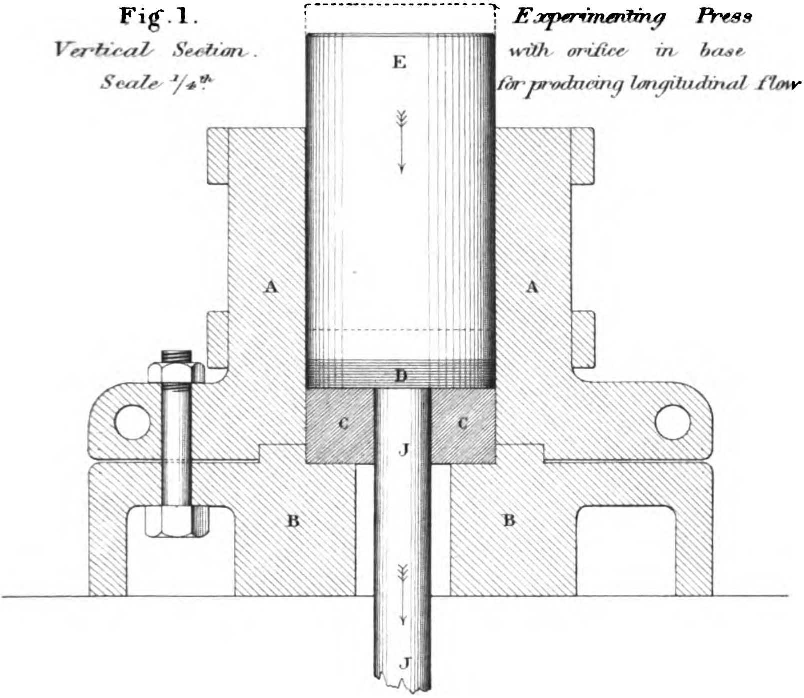
(Proceedings Inst. M. E. 1867. Page 80.) *Scale* 1/200th.

FLOW OF SOLIDS.

Plate 22.

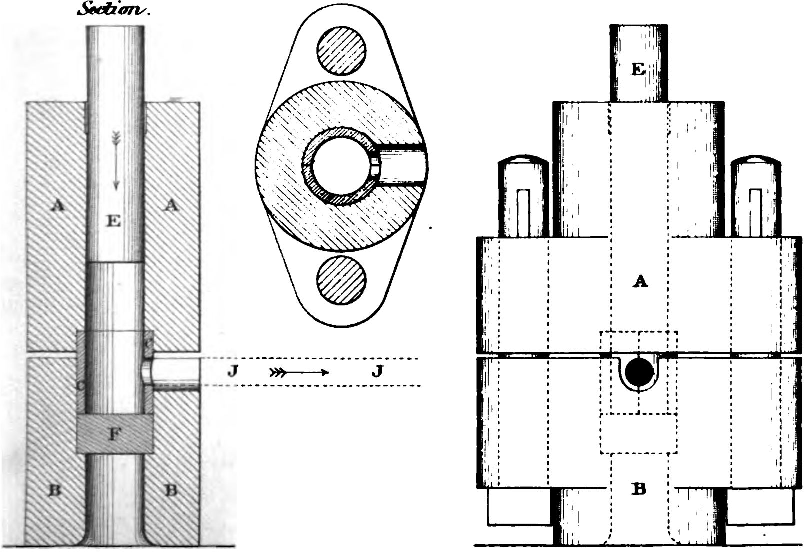
Fig. 1. *Vertical Section.* *Scale 1/4th.*

Experimenting Press with orifice in base for producing longitudinal flow.



Experimenting Press with orifice in side for producing lateral flow.

Fig. 2. *Vertical Section.* **Fig. 3.** *Sectional Plan.* **Fig. 4.** *Front Elevation.*



(Proceedings Inst. M. E. 1867. Page 114.)

Scale 1/4th.

Fig. 5. *Longitudinal Section of Jet produced from 10 Discs of Lead forced to flow through concentric circular orifice.*

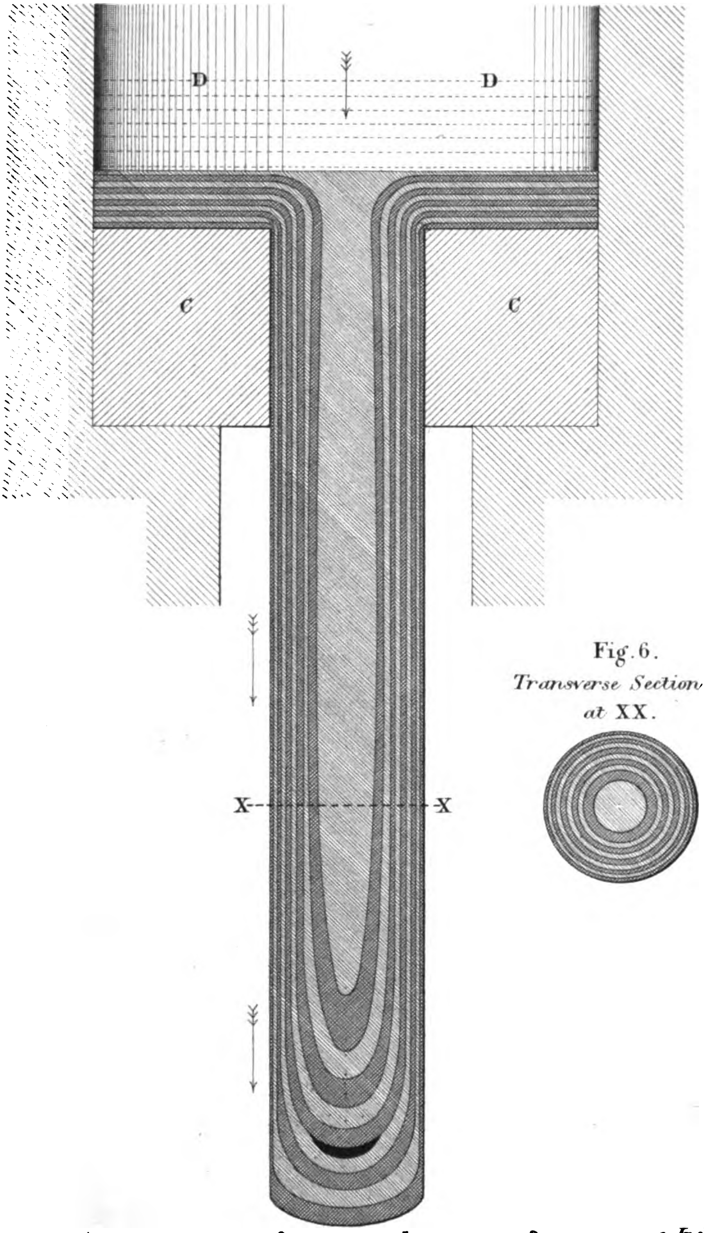


Fig. 6.
Transverse Section at XX.

Scale 2/3rds 0 1 2 3 *Inches.*

(Proceedings Inst. M.E. 1867. Page 114.)

Fig. 7. *Hollow Jet produced from 4 Discs of Lead flowing through concentric circular orifice and forming contracted vein.*

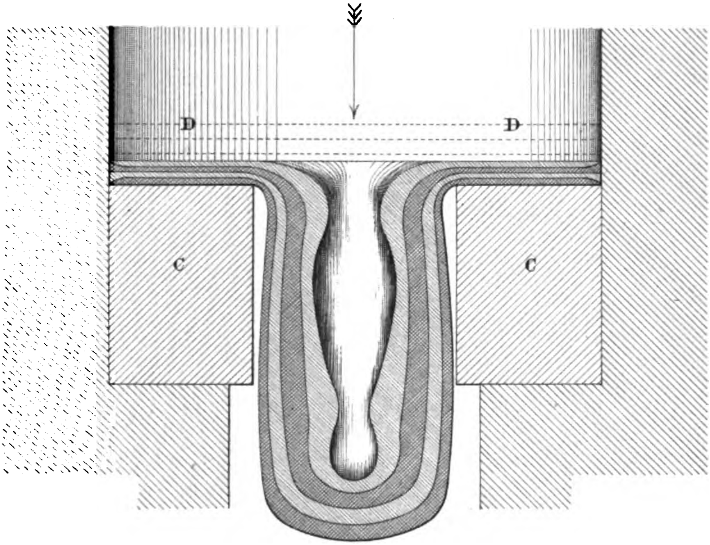
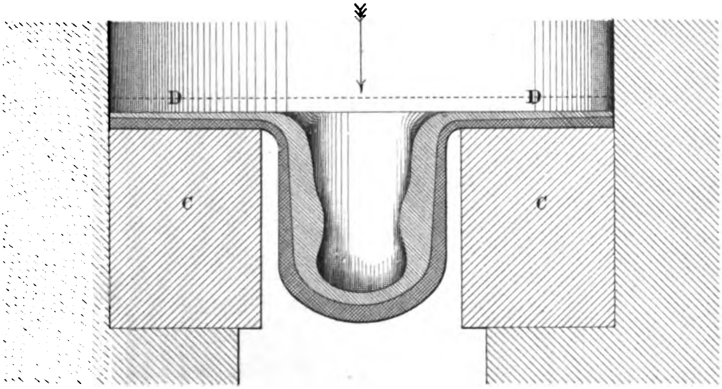


Fig. 8. *Hollow Jet produced from 2 Discs of Lead flowing through concentric circular orifice and forming contracted vein.*



Scale 2/3rds

(Proceedings Inst. M.E. 1867. Page 114.)

FLOW OF SOLIDS. Plate 25.

Jets produced from 6 Discs of Lead
flowing through two eccentric circular orifices of different sizes.

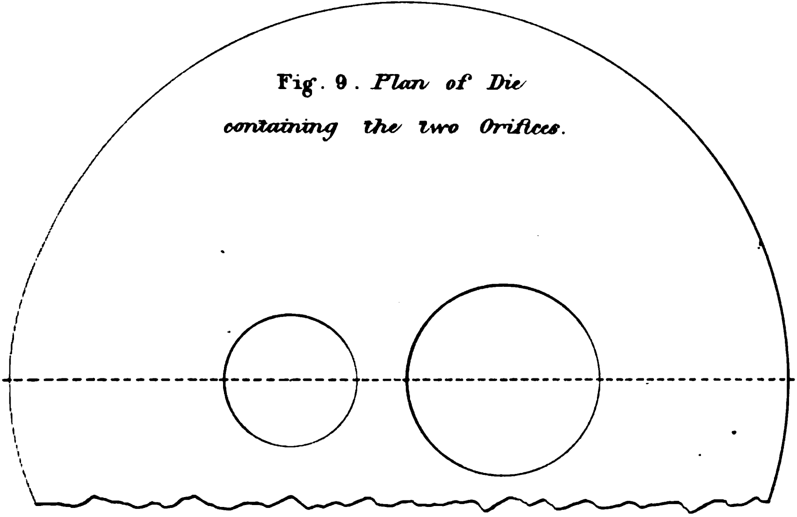
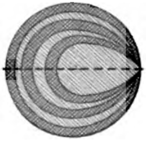


Fig. 9. *Plan of Die*
containing the two Orifices.

Transverse Sections of Jets produced.

Nearest to orifices.

Fig. 10.



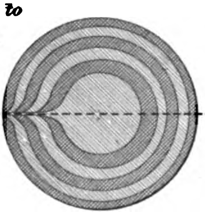
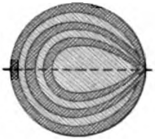


Fig. 11.

Intermediate distance.

Fig. 12.



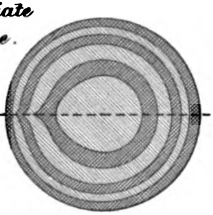
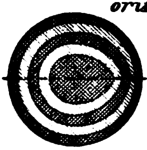


Fig. 13.

Furthest from orifices.

Fig. 14.



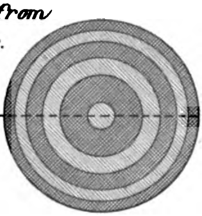


Fig. 15.

(Proceedings Inst. M. E. 1867. Page 114.) *Scale full size.*

FLOW OF SOLIDS.

Plate 26.

Jet produced from 19 Discs of Lead flowing through lateral square orifice.

Fig. 16. *Vertical Section of Press and Longitudinal Section of Jet.*

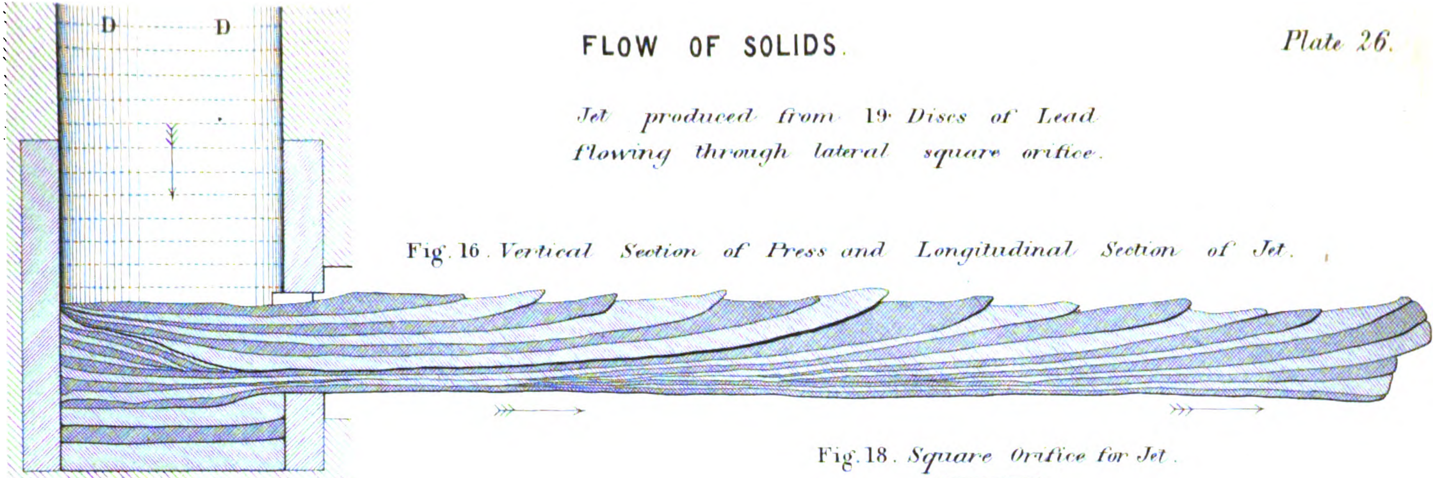


Fig. 18. *Square Orifice for Jet.*

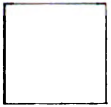
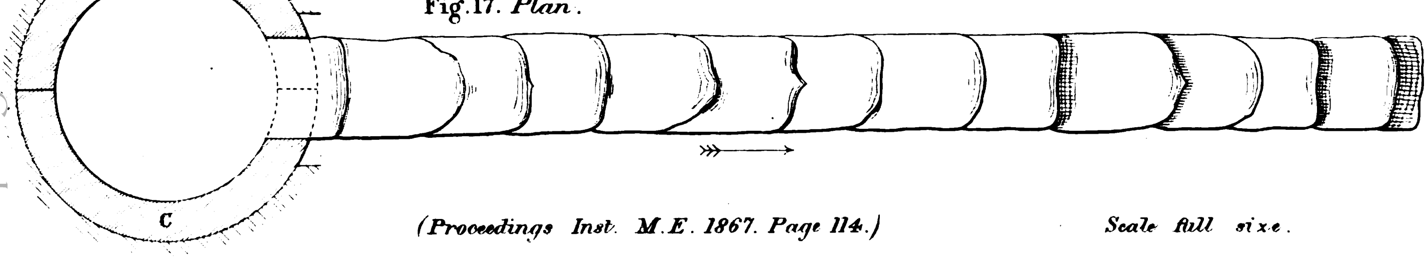


Fig. 17. *Plan.*



(Proceedings Inst. M.E. 1867. Page 114.)

Scale full size.

FLOW OF SOLIDS. *Plate 27.*

Transverse Sections of Compound Lateral Jet produced from portion of cylindrical jet in Fig. 5.

Fig. 19. *Furthest from orifice.*

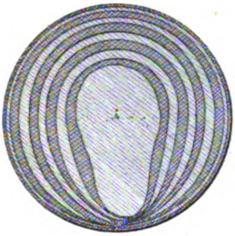


Fig. 20. *Nearer to orifice.*

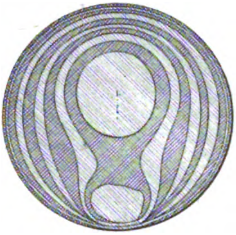


Fig. 21. *Still nearer to orifice.*

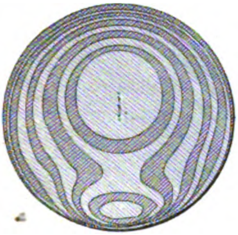


Fig. 22. *Nearest to orifice.*

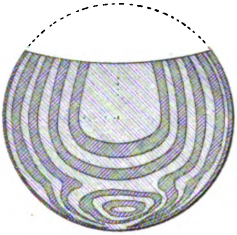
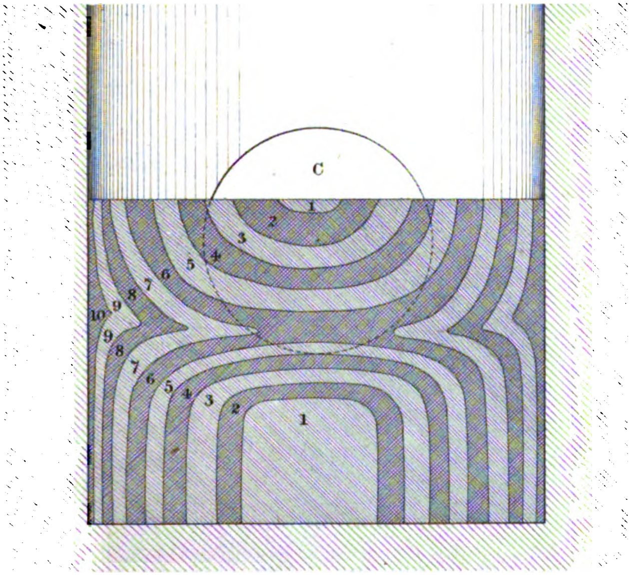


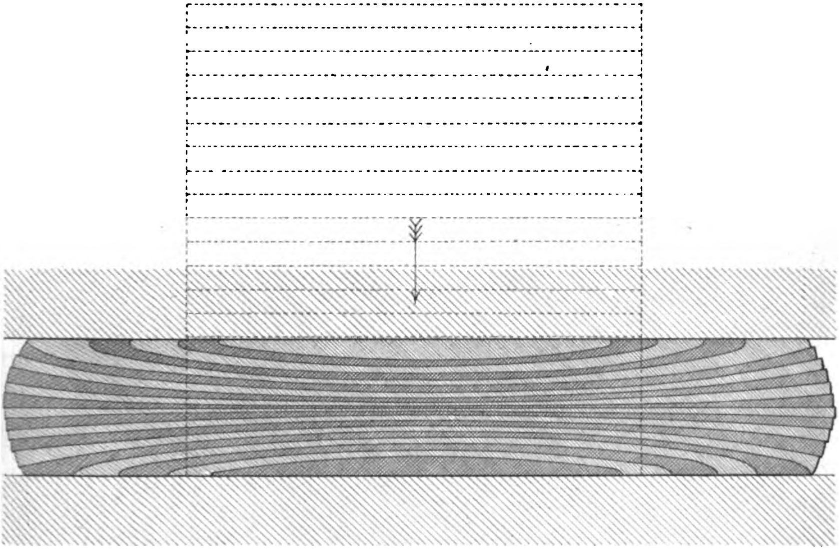
Fig. 23. *Vertical Section of original Block after production of Jet.*



(Proceedings Inst. M. E. 1867. Page 114.) *Scale double full size.*

Longitudinal Compression or Jumping-up of Cylinder composed of 20 Discs of Lead, not confined in die.

Fig. 24. *Longitudinal Section through centre of cylinder.*



Longitudinal Compression or Jumping-up of Cylinder composed of 12 Concentric Rings of Lead, not confined in die.

Fig. 25. *Longitudinal Section before compression.*

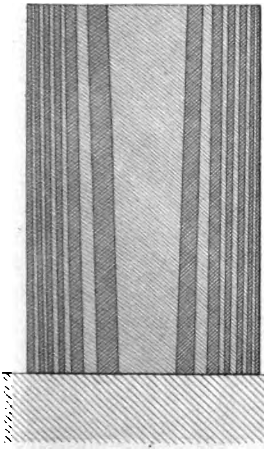
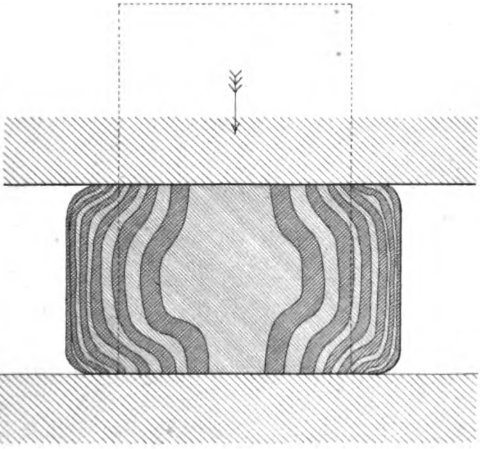


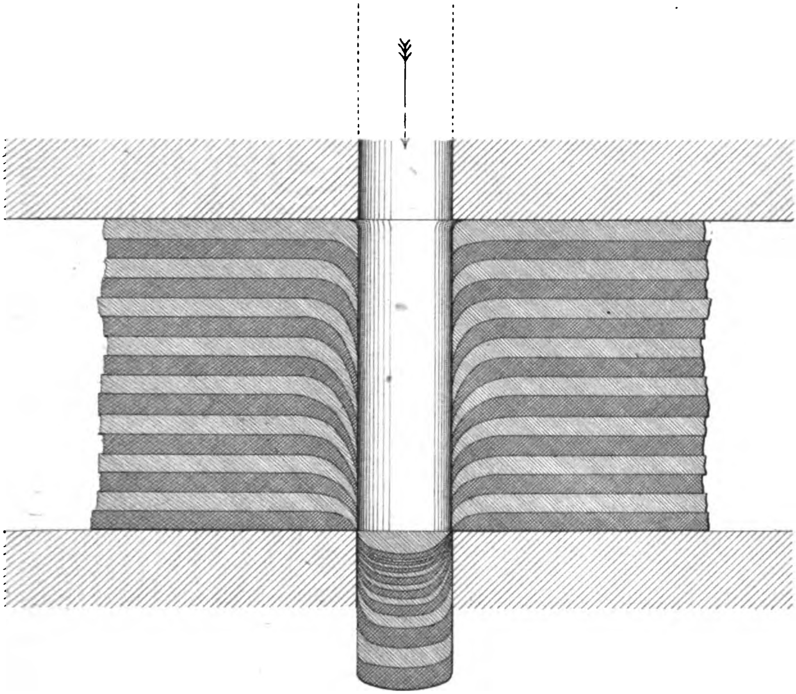
Fig. 26. *Longitudinal Section after compression.*



(Proceedings Inst. M. E. 1867. Page 114.) *Scale full size.*

FLOW OF SOLIDS. *Plate 29.*

Fig. 27. *Punching of Square Block of Lead composed of 16 plates, 4·72 inches square.*



Punching of Circular Blocks of Lead composed of 8 plates, 2·36 inches diameter, punched on solid base, without die.

Fig. 28.

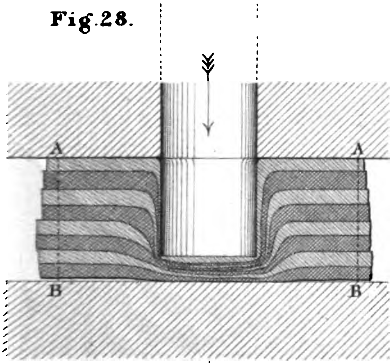
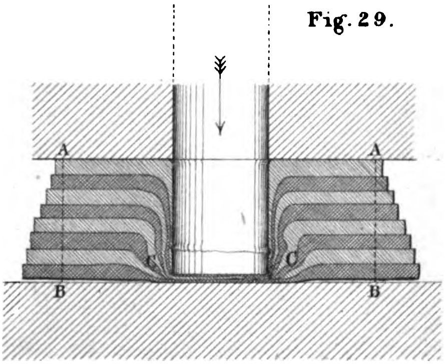


Fig. 29.



Scale $^2/_3$*rds*

(Proceedings Inst. M. E. 1867. Page 114.)

Fig. 30. *Longitudinal Section of Jet produced from 2 Discs of Iron forced to flow at a red heat through a concentric circular orifice.*

Scale 6/10ths.

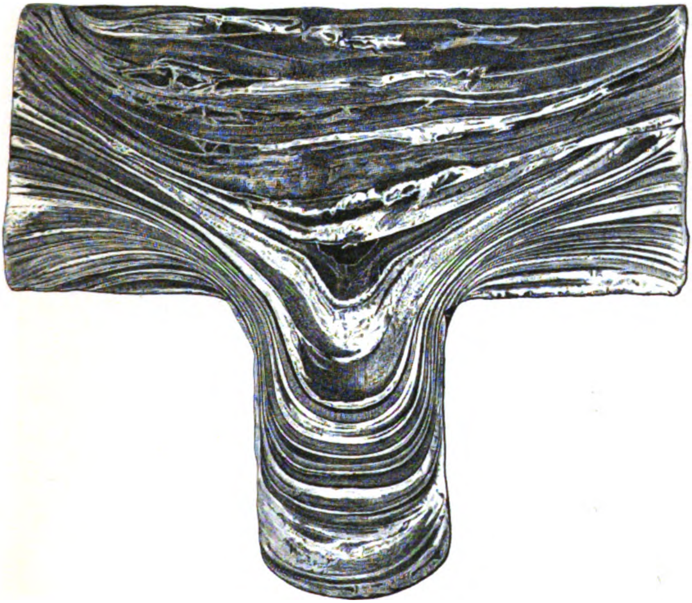
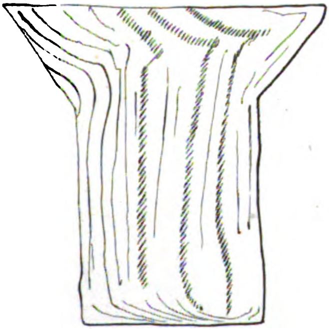


Fig. 31. *Longitudinal Section of Rivet.*

Scale 4 times full size.



(Proceedings Inst. M. E. 1867. Page 114.)

FLOW OF SOLIDS.

Fig. 32. *Longitudinal Section of armour-plate Bolt, forged in die with screw thread. Scale 1/3rd.*

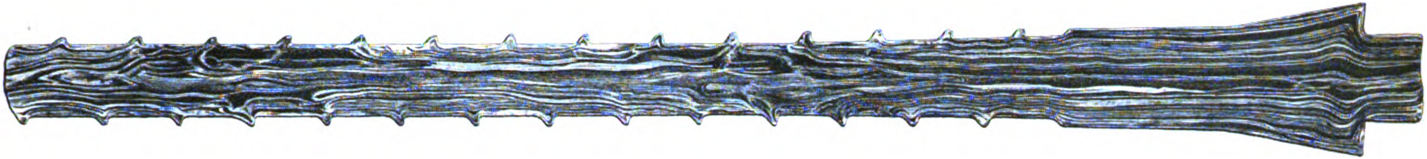
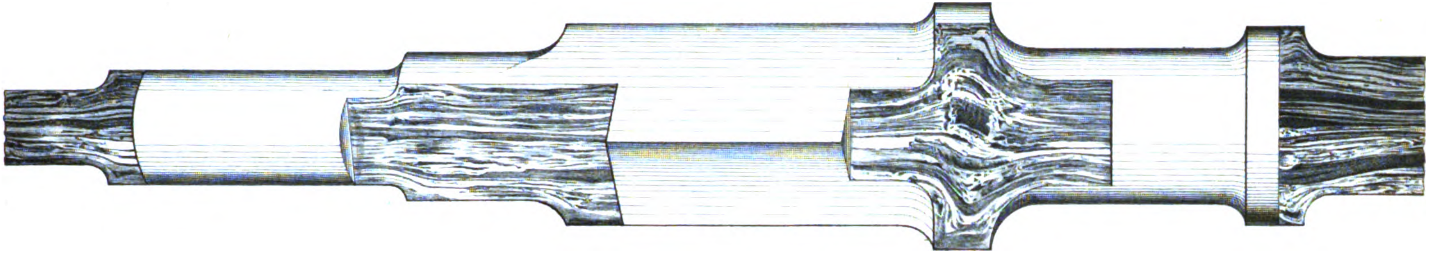


Fig. 33. *Sections of Forged Shaft, jumped-up in centre, and forged to different dimensions. Scale 1/3rd.*



(Proceedings Inst. M. E. 1867. Page 114)

Wrought-Iron Wheel Nave, forged in dies at Messrs. Arbel's.

Fig. 34. *Transverse Section of finished forging.*

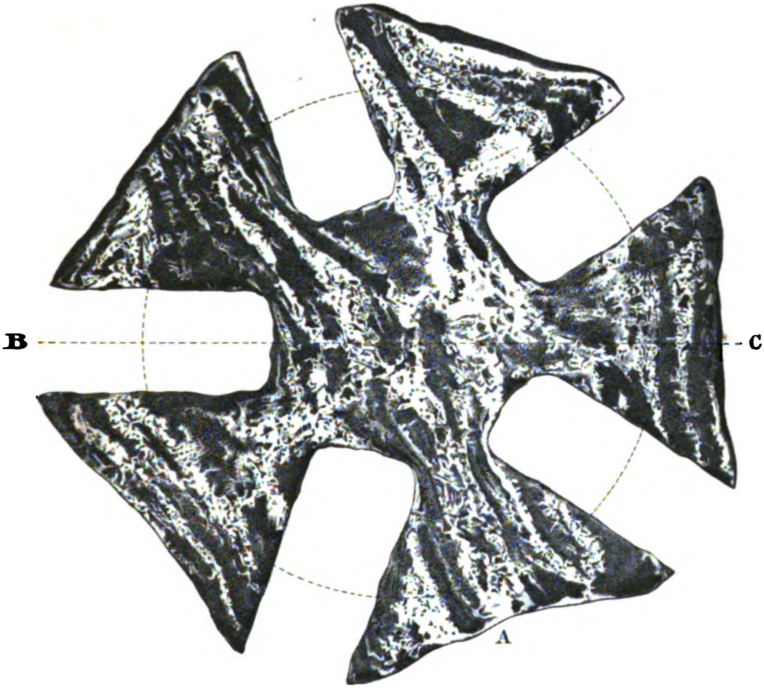
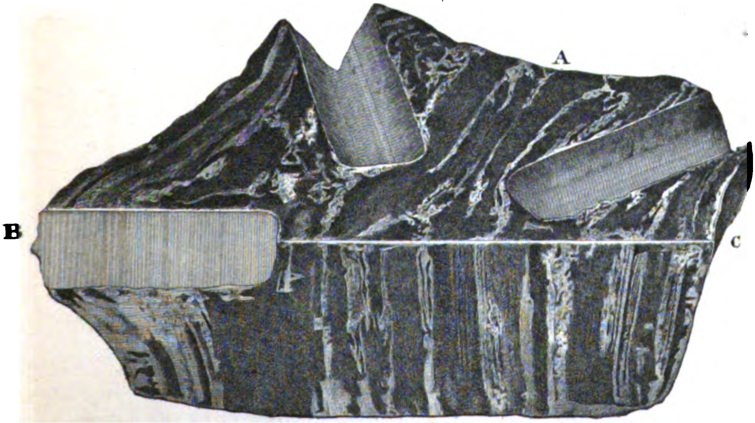


Fig. 35. *Perspective view showing section along* **B C.**



(Proceedings Inst. M. E. 1867. Page 114.) *Scale 8/10ths.*

Forge for Puddling Machinery at Dowlais Iron Works.

Fig. 1. *Longitudinal Section.*

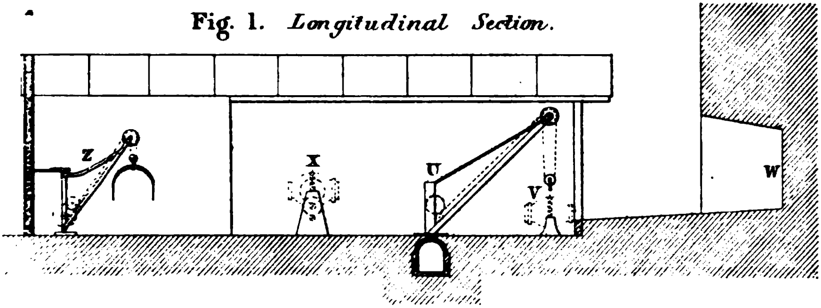


Fig. 2. *Plan.*

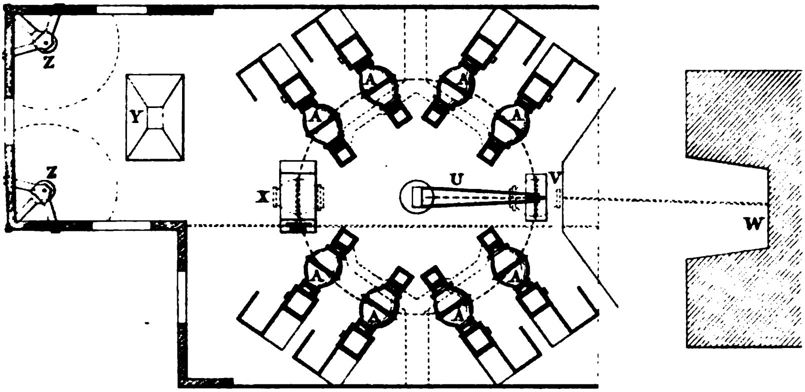
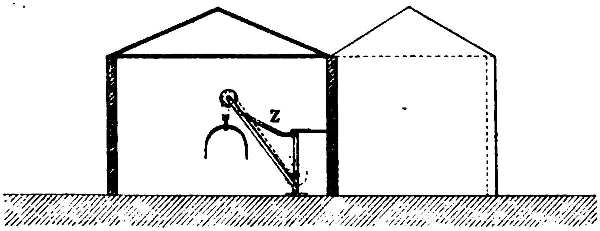


Fig. 3. *Transverse Section.*



(Proceedings Inst. M.E. 1867. Page 151.) *Scale 1/400th.*

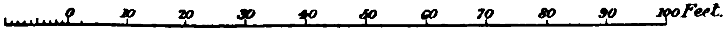


Fig. 4. *End Elevation of Driving Machinery driving a pair of Puddling Vessels.*

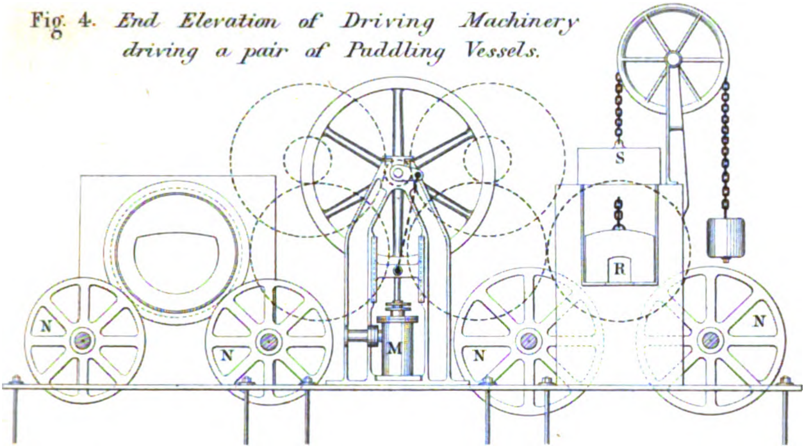
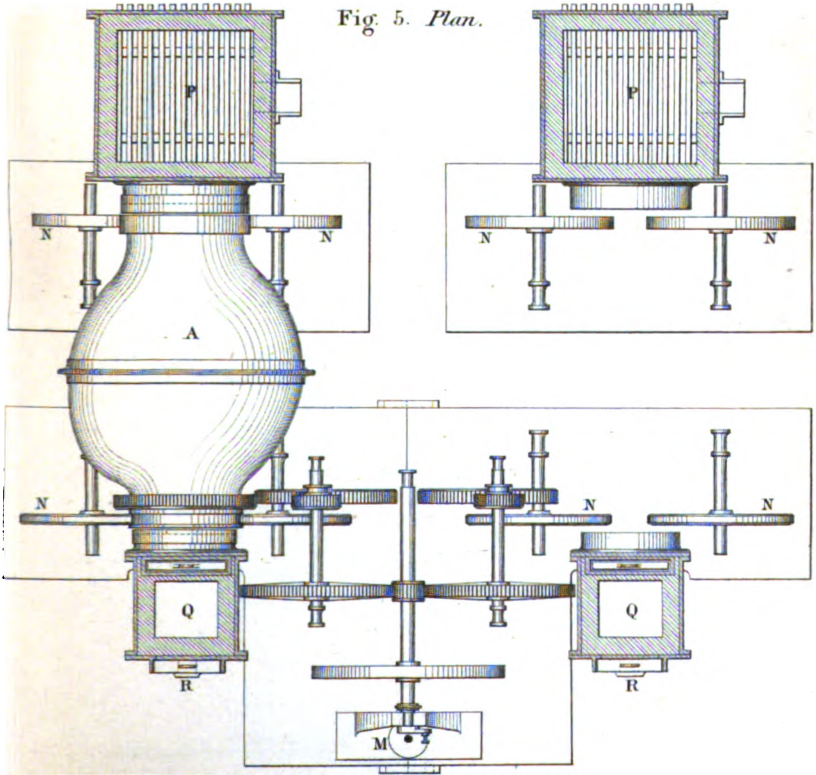


Fig. 5. *Plan.*



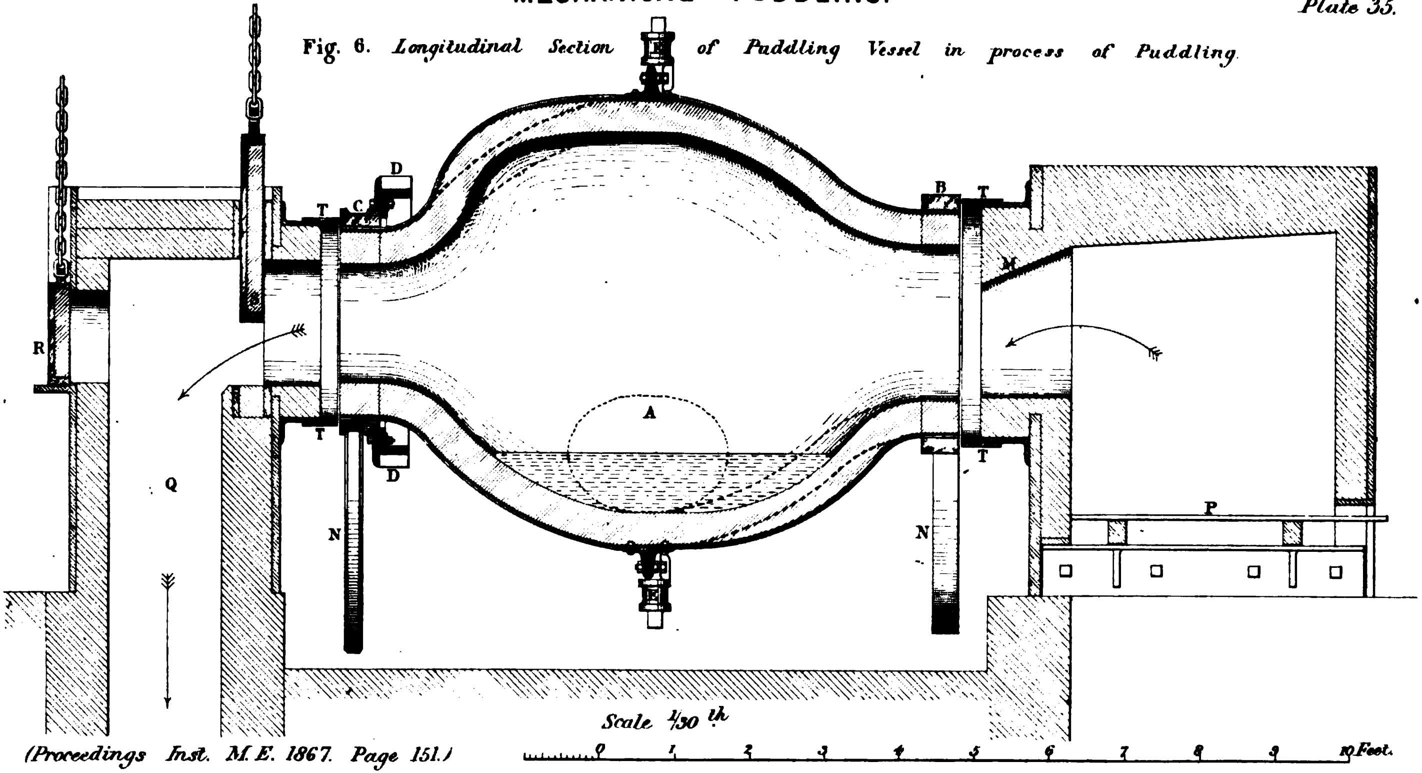
(Proceedings Inst. M.E. 1867. Page 151.)

Scale 1/60th.

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 Feet.

MECHANICAL PUDDLING.

Fig. 6. *Longitudinal Section of Puddling Vessel in process of Puddling.*



(Proceedings Inst. M. E. 1867. Page 151.)

MECHANICAL PUDDLING.

Plate 36.

Fig. 7. *End Elevation of Puddling Vessel in working position.*

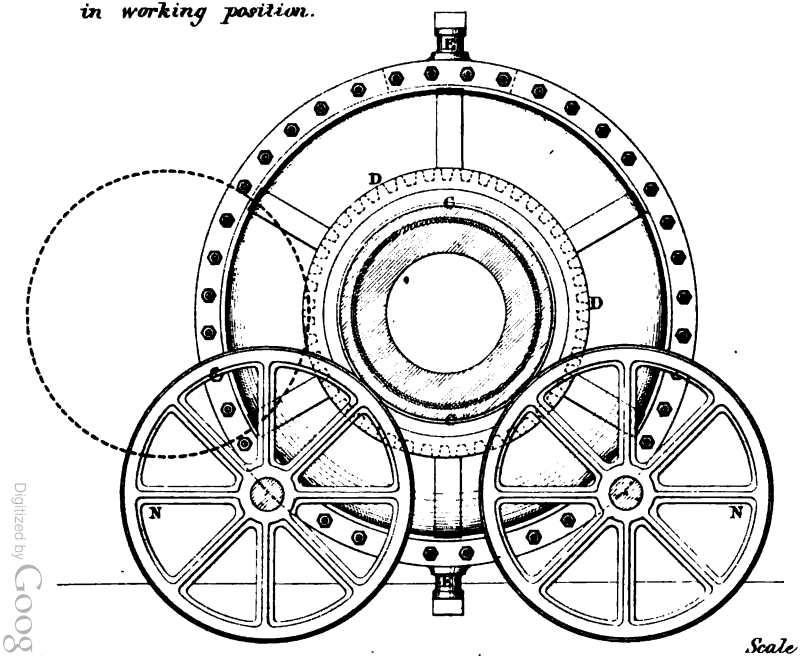
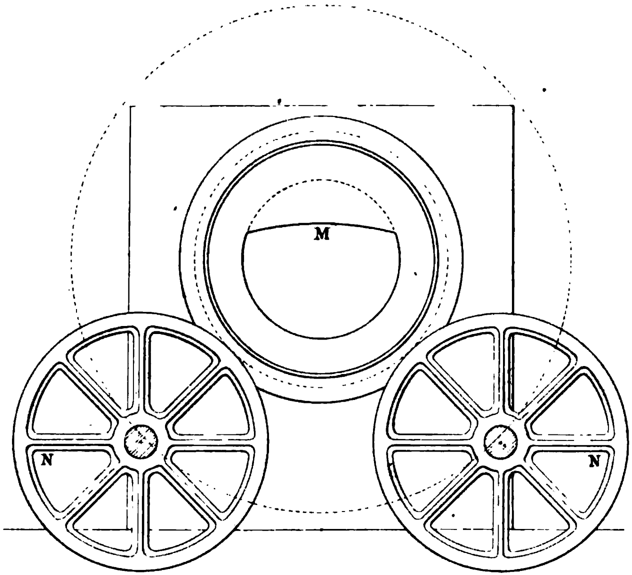


Fig. 8. *Elevation of Mouth of Firebox, with Puddling Vessel removed.*



Scale 1/30 th

0 1 2 3 4 5 6 7 8 9 10 Feet.

(Proceedings Inst. M.E. 1867. Page 151.)

MECHANICAL PUDDLING.

Puddling Vessel in position for receiving the charge.

Fig. 9. *Side Elevation.*

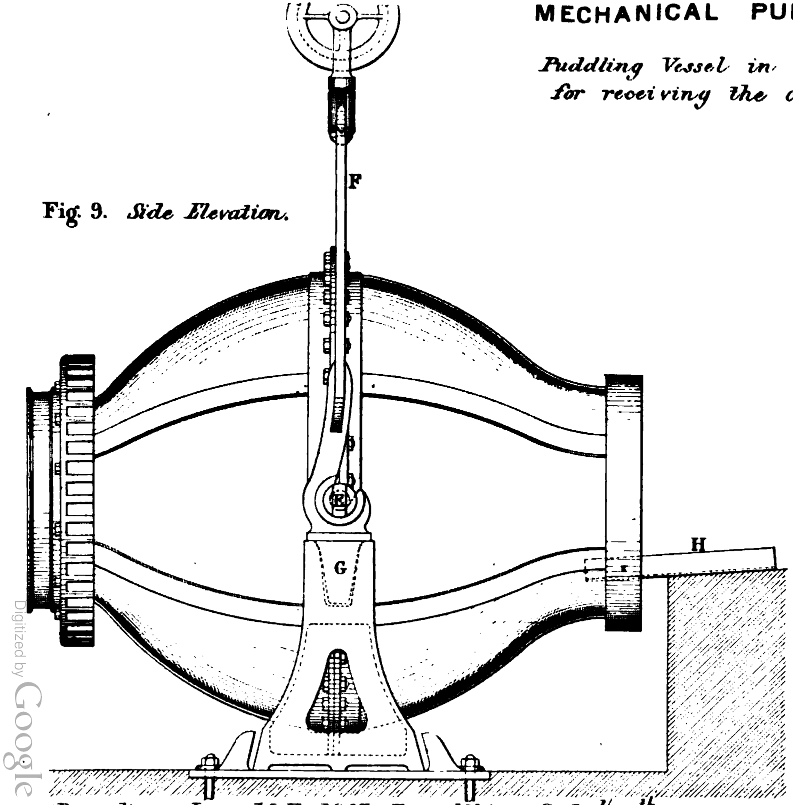
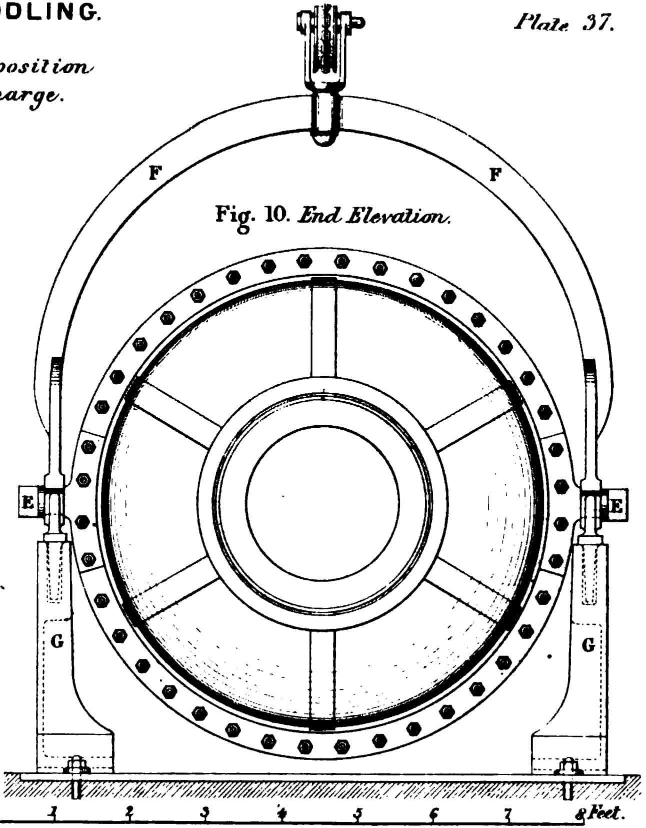


Fig. 10. *End Elevation.*



(Proceedings Inst. M. E. 1867. Page 151.) *Scale 1/30th.*

MECHANICAL PUDDLING.

Plate 38.

Puddling Vessel
in position for tipping
to discharge the Puddled Ball.

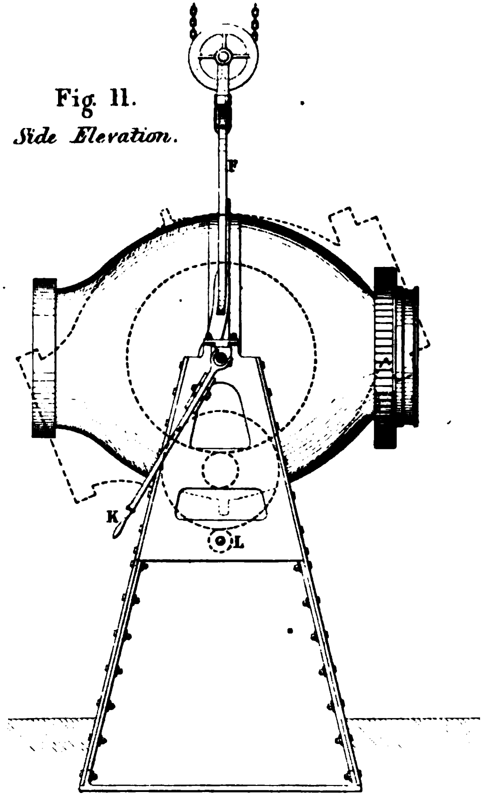


Fig. 11.
Side Elevation.

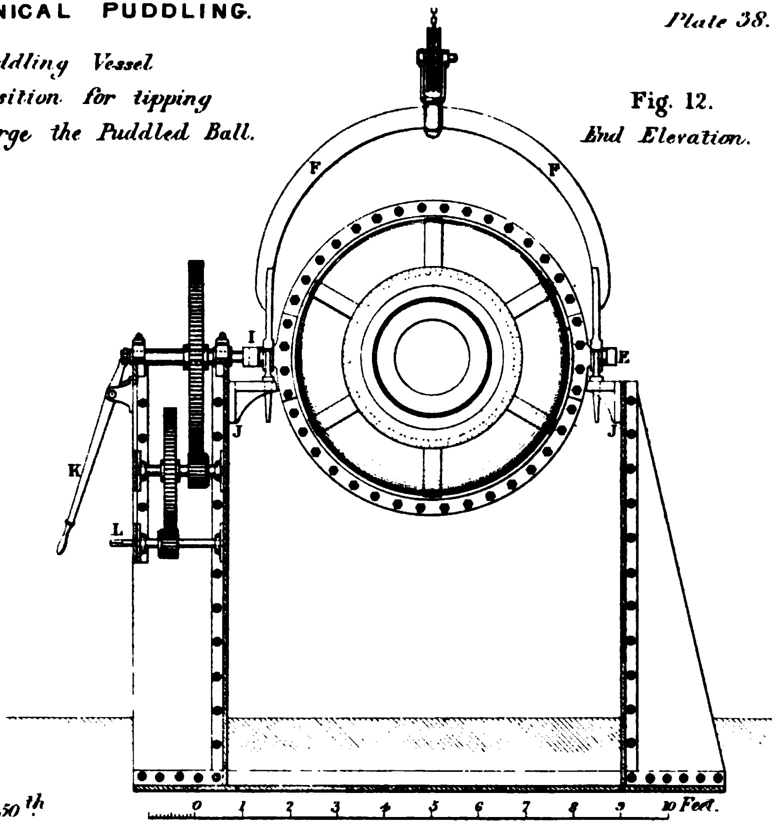


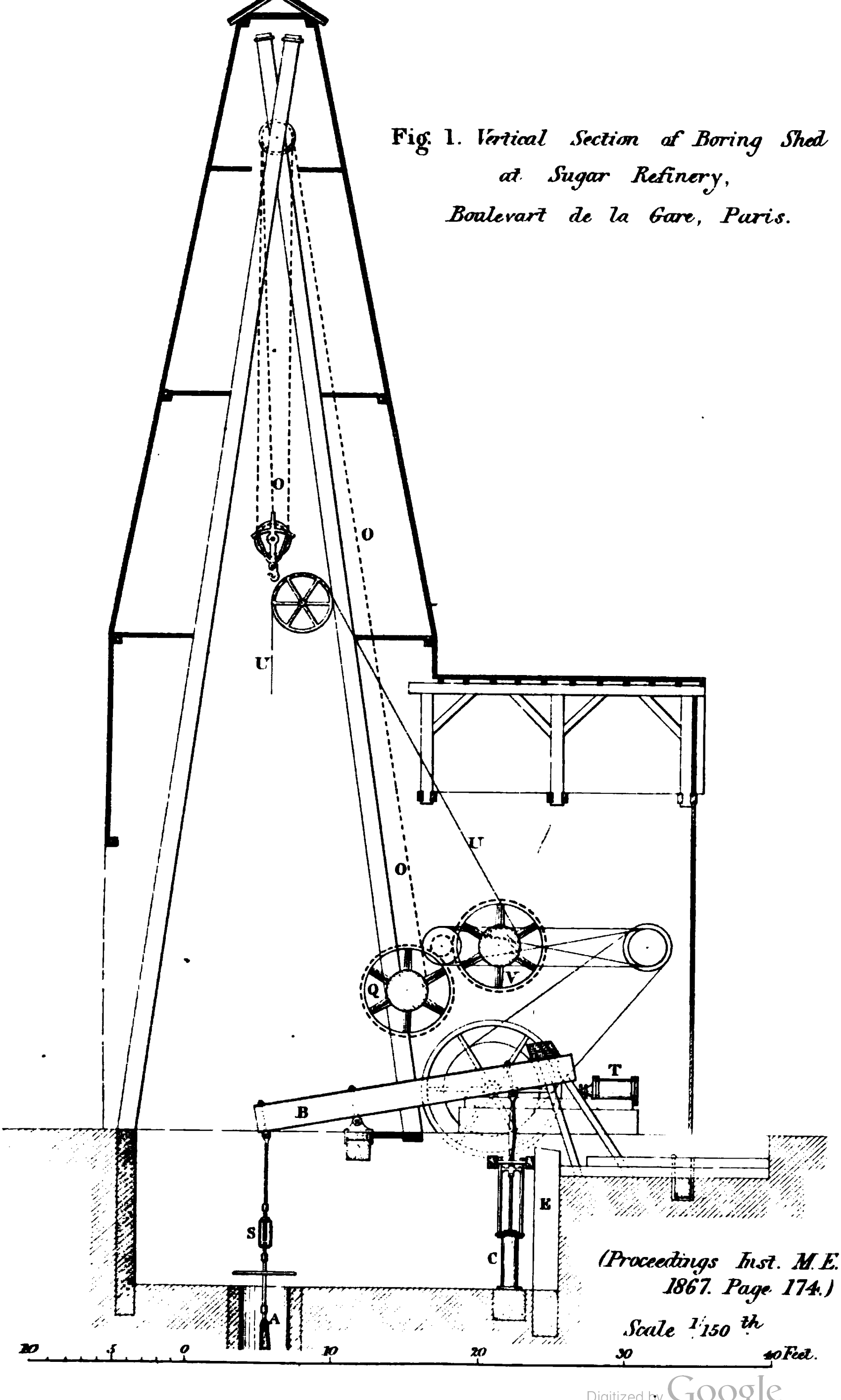
Fig. 12.
End Elevation.

Scale $^1/_{50}$th.

(Proceedings Inst. M.E. 1867. Page 151.)

BORING ARTESIAN WELLS. *Plate 39.*

Fig. 1. *Vertical Section of Boring Shed at Sugar Refinery, Boulevart de la Gare, Paris.*

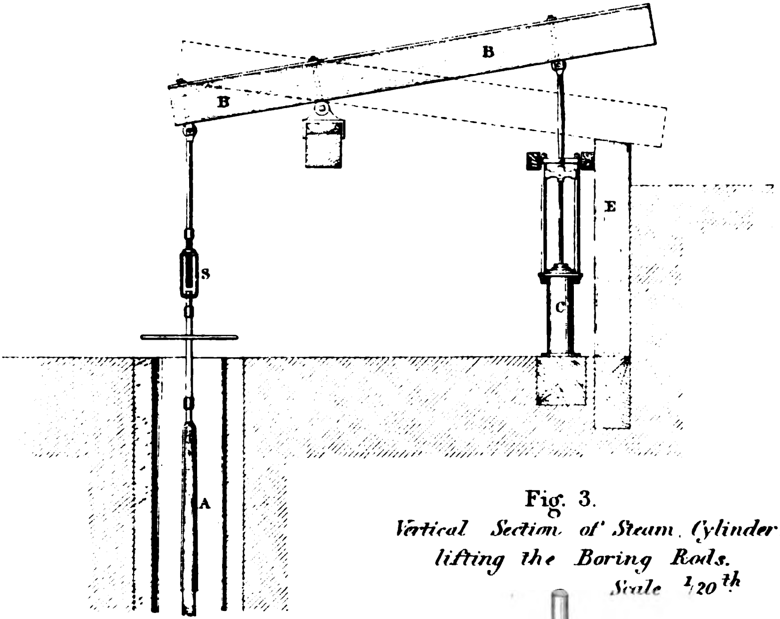


(Proceedings Inst. M.E. 1867. Page 174.)

Scale 1/150 th

BORING ARTESIAN WELLS. *Plate 40.*

Fig. 2. *Vertical Section of Well and Boring Apparatus.* *Scale 1/100th.*



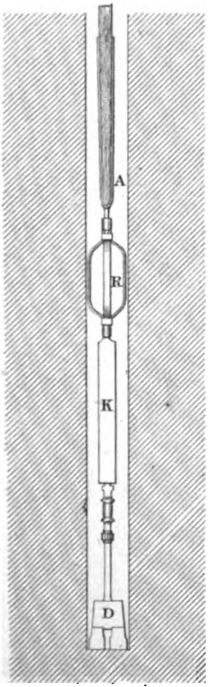
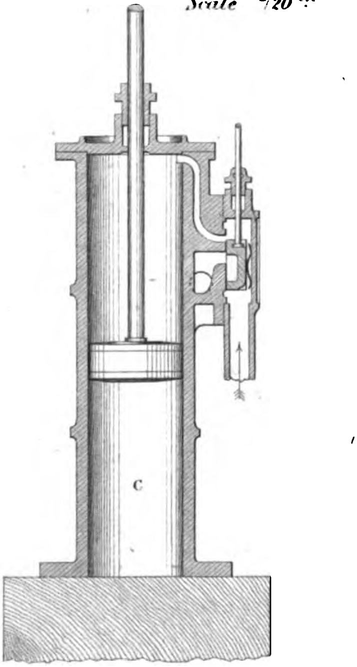


Fig. 3.

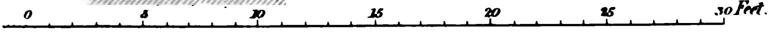
Vertical Section of Steam Cylinder lifting the Boring Rods.

Scale 1/20th.



(Proceedings Inst. M.E. 1867. Page 174.)

Scale 1/100th.



BORING ARTESIAN WELLS. *Plate 41.*

Fig. 4. *Lantern for guiding lower end of Boring Rod.*
Scale 1/20th

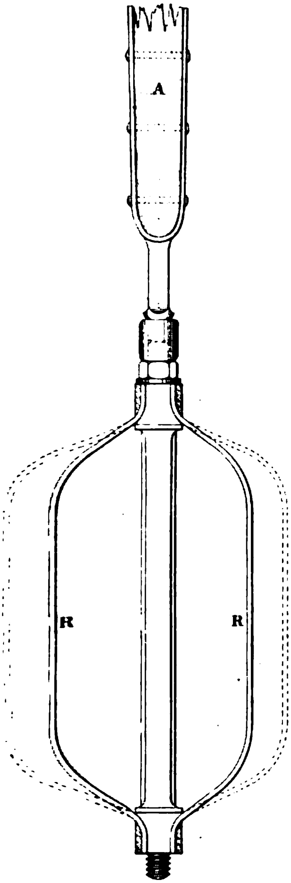
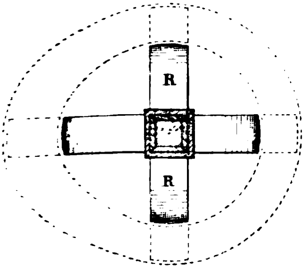


Fig. 5. *Plan of Lantern.*



Scale 1/20th

Couplings of Boring Rods.

Fig. 6. *Solid Screwed Socket.*

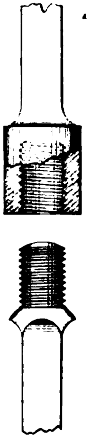
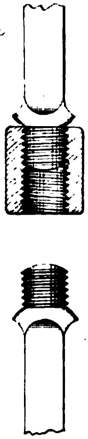


Fig. 7. *Separate Screwed Collar.*

Scale 1/10th



Tools for recovering broken boring rods &c.

Fig. 8. *Claw.*

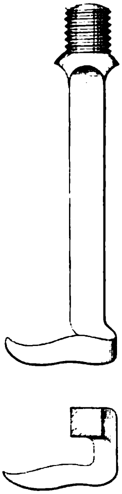


Fig. 9. *Conical Screwed Socket.*

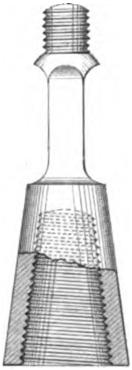


Fig. 10. *Locking Clip to prevent unscrewing of Couplings. Scale 1/10th.*

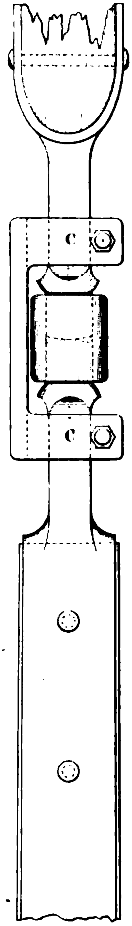
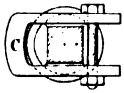


Fig. 11. *Plan of Clip.*



Scale 1/10th.

(Proceedings Inst. M.E. 1867. Page 174.)

Free-Falling Tool liberated by Reaction.

Boring Rod ascending, and raising the Tool.

Fig. 12. *Side View.*

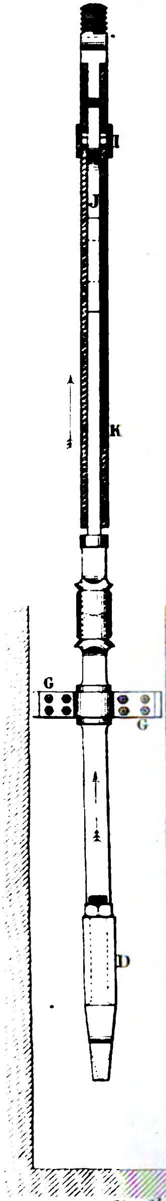


Fig. 13. *Front View.*

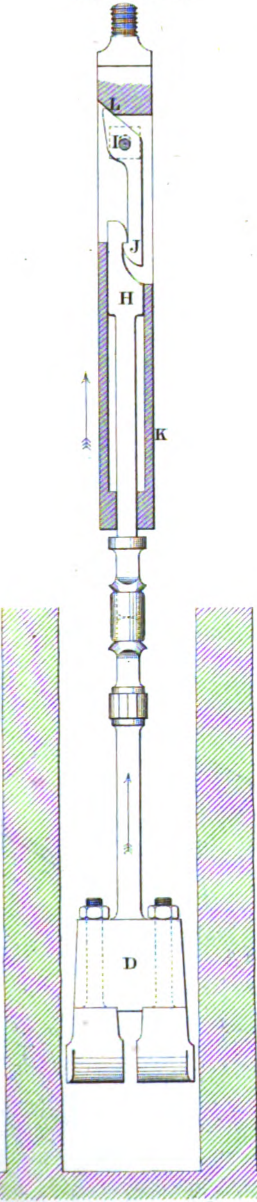


Fig. 14. *At moment of Shock.*

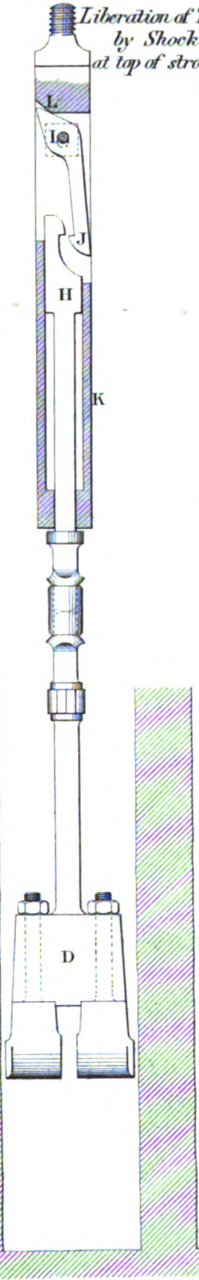
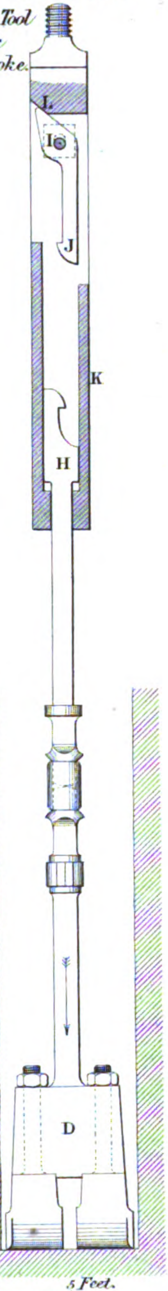


Fig. 15. *Tool fallen.*



Scale $^1/_{30}$ *th* 0 1 2 3 4 5 *Feet.*

(Proceedings Inst. M. E. 1867. Page 174.)

BORING ARTESIAN WELLS.

Plate 43.

Free-Falling Tool liberated by Disengaging-Rod.

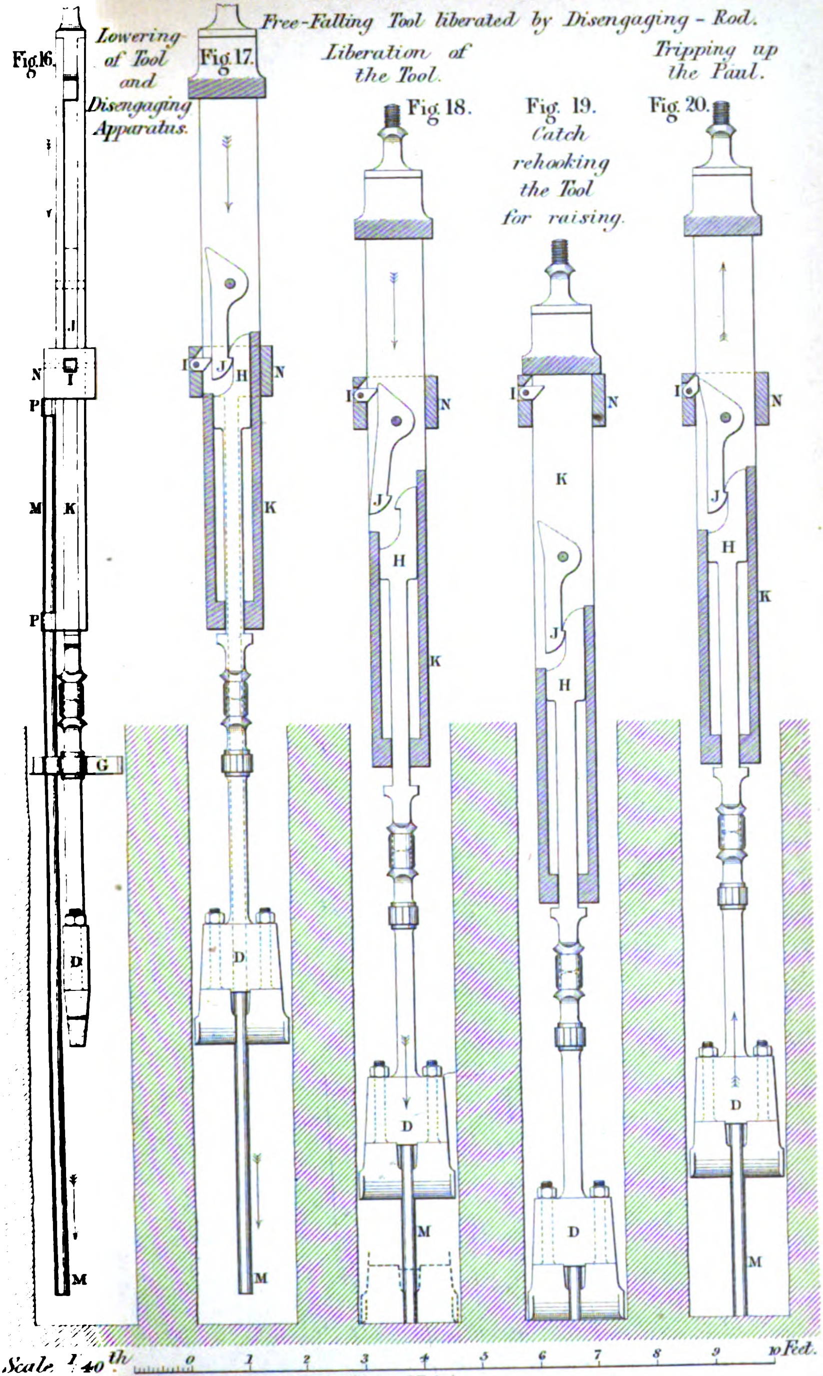


Fig. 16. Fig. 17. Lowering of Tool and Disengaging Apparatus.

Fig. 18. Liberation of the Tool.

Fig. 19. Catch rehooking the Tool for raising.

Fig. 20. Tripping up the Paul.

Scale 1/40th

(Proceedings Inst. M.E. 1867. Page 174.)

BORING ARTESIAN WELLS. *Plate 44*

Free-Falling Tool liberated by Reaction.
sinking well of 19 inches diameter at Sugar Refinery.

Fig. 23. *Side Elevation.*

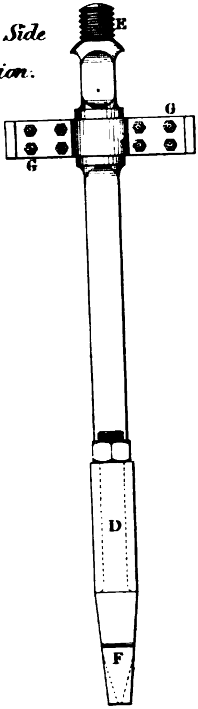


Fig. 24. *Front Elevation.*

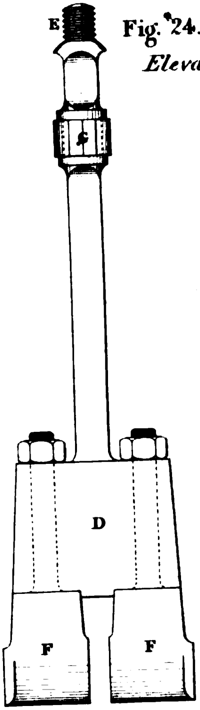
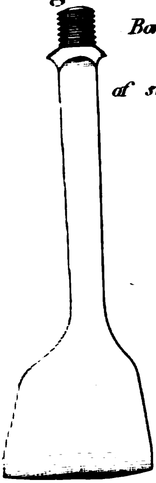


Fig. 21.



Boring Tools for wells of small diameter.

Fig. 22.

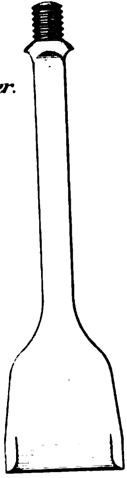
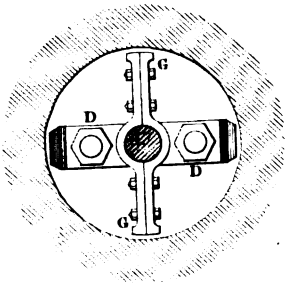


Fig. 25. *Plan.*



(Proceedings Inst. M. E. 1867. Page 174.)

Scale 1/20th.

BORING ARTESIAN WELLS. *Plate 45.*

Free-Falling Tool liberated by Disengaging-Rod, sinking well of 47 *inches diameter at Butte-aux-Cailles.*

Fig. 26. *Side Elevation.*

Fig. 27. *Front Elevation.*

Fig. 28. *Plan of Guide.*

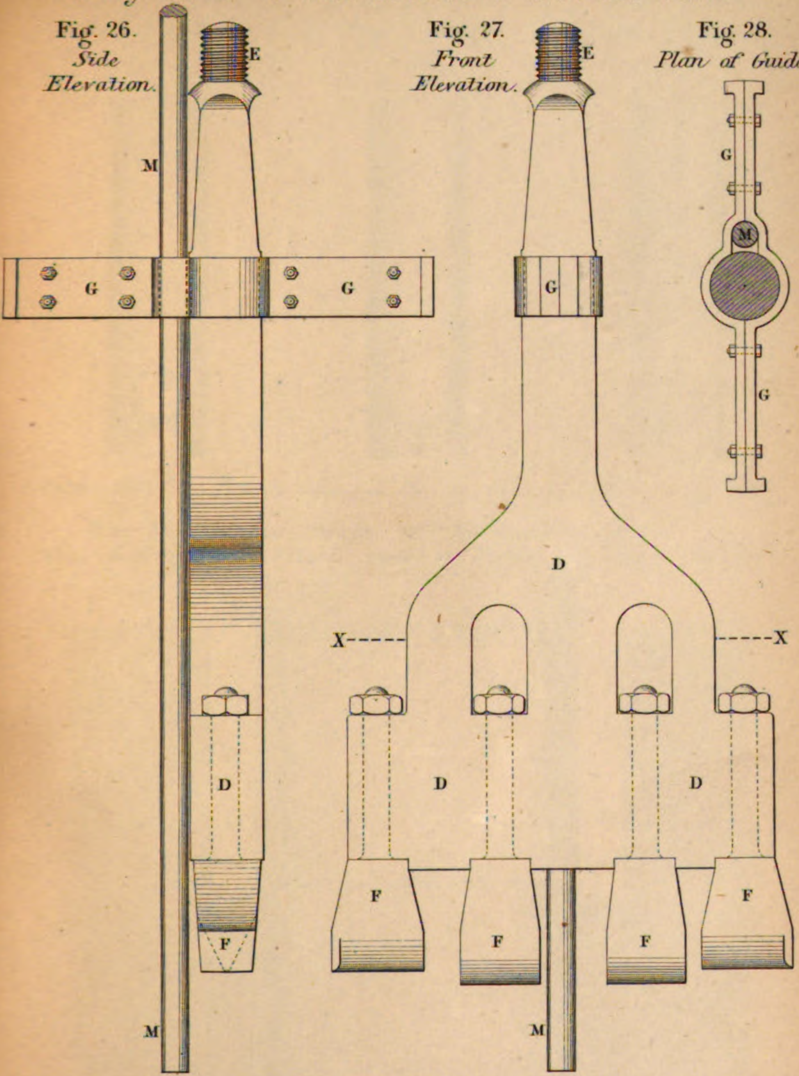
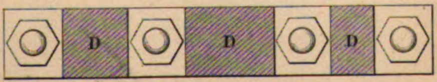
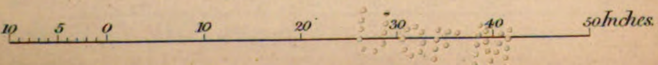


Fig. 29. *Sectional Plan at* XX.



(Proceedings Inst. M. E. 1867. Page 174.)

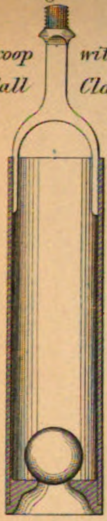
Scale 1/20th.



BORING ARTESIAN WELLS. *Plate 46.*

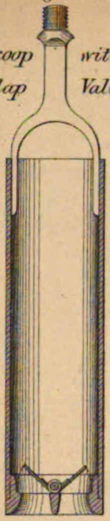
Scoops for clearing bottom of Bore-hole. Scale 1/20th.

Fig. 30.



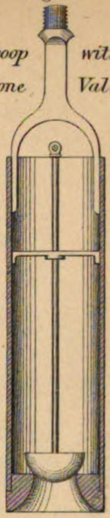
Scoop with Ball Clack.

Fig. 31.



Scoop with Flap Valves.

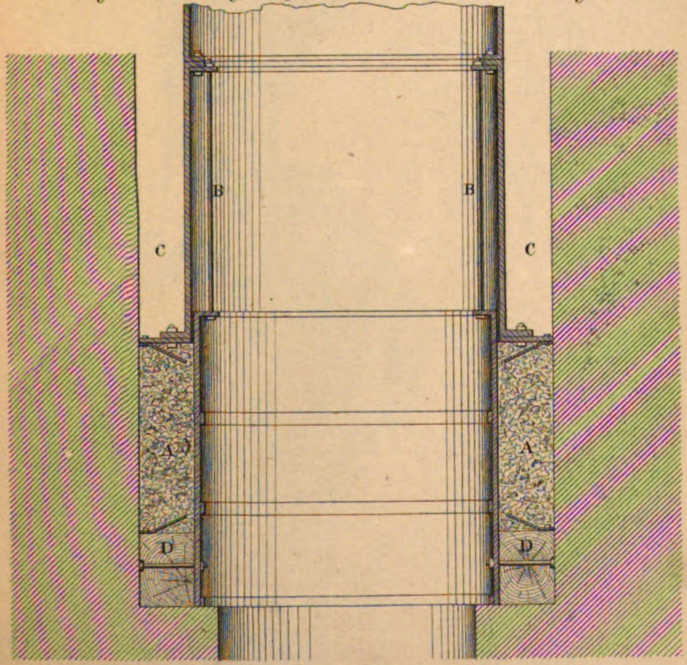
Fig. 32.



Scoop with Cone Valve.

Scale 1/20th. 10 5 0 10 20 30 40 *Inches.*

Fig. 33. *Vertical Section of Kind's Moss Box for making water-tight joint at bottom of Tubing. Scale 1/40th.*



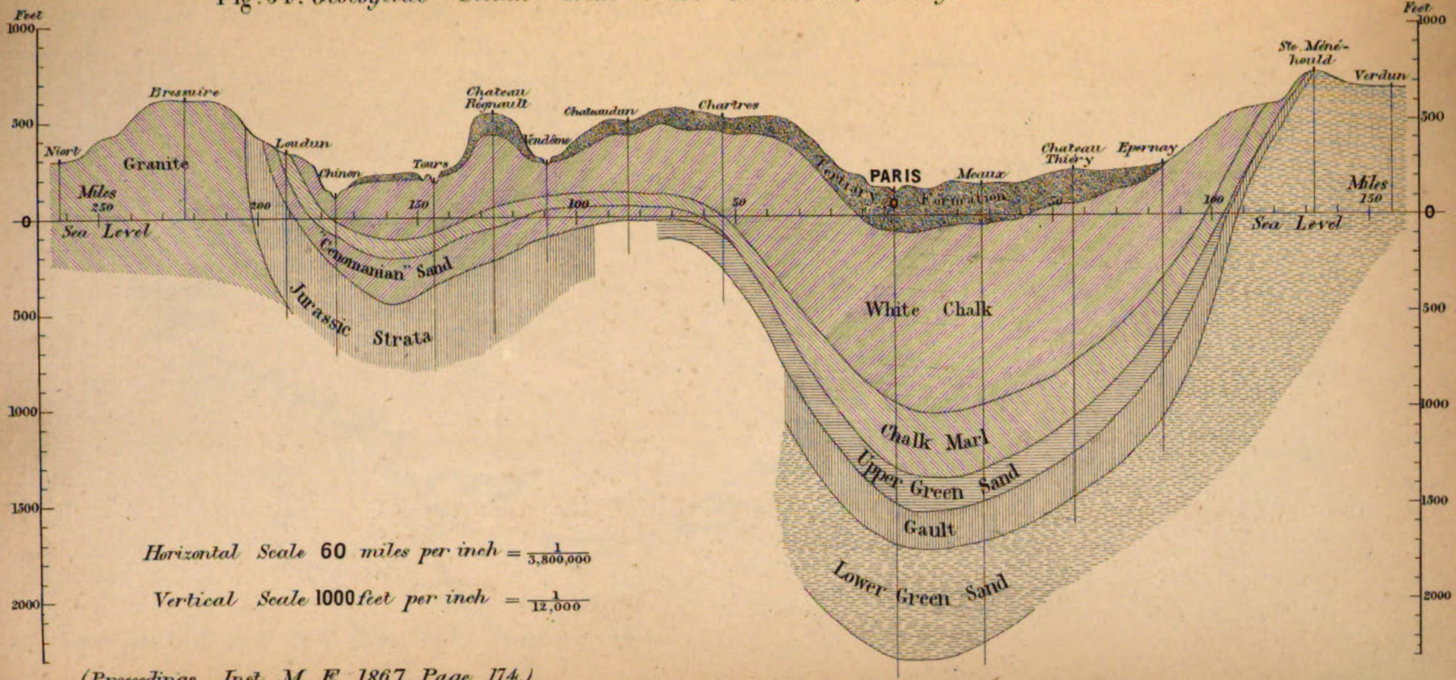
Scale 1/40th 0 1 2 3 4 5 6 7 8 *Feet.*

(Proceedings Inst. M. E. 1867. Page 174.)

BORING ARTESIAN WELLS.

Plate 47.

Fig. 34. *Geological Section from Niort to Verdun, through the Paris basin.*



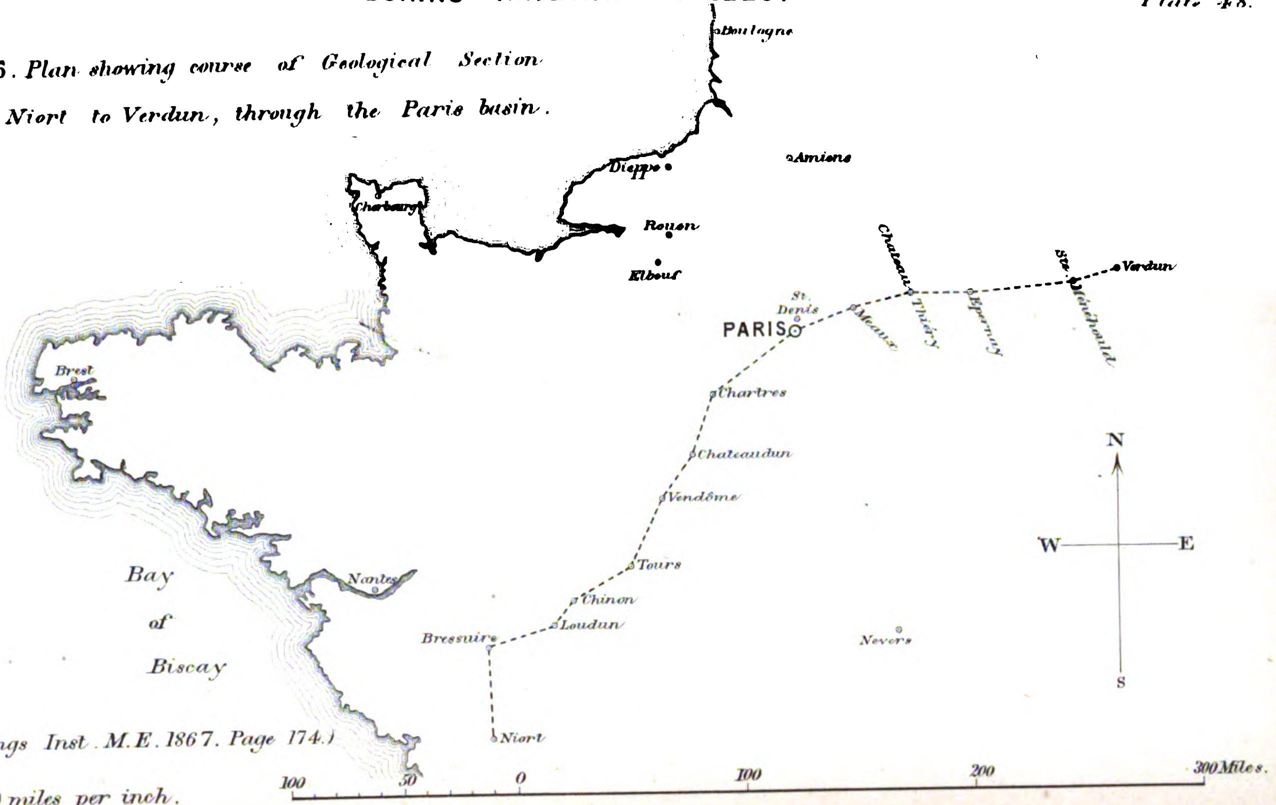
Horizontal Scale 60 *miles per inch* = $\frac{1}{3,800,000}$

Vertical Scale 1000 *feet per inch* = $\frac{1}{12,000}$

(Proceedings Inst. M. E. 1867. Page 174.)

BORING ARTESIAN WELLS.

Fig. 35. *Plan showing course of Geological Section from Niort to Verdun, through the Paris basin.*

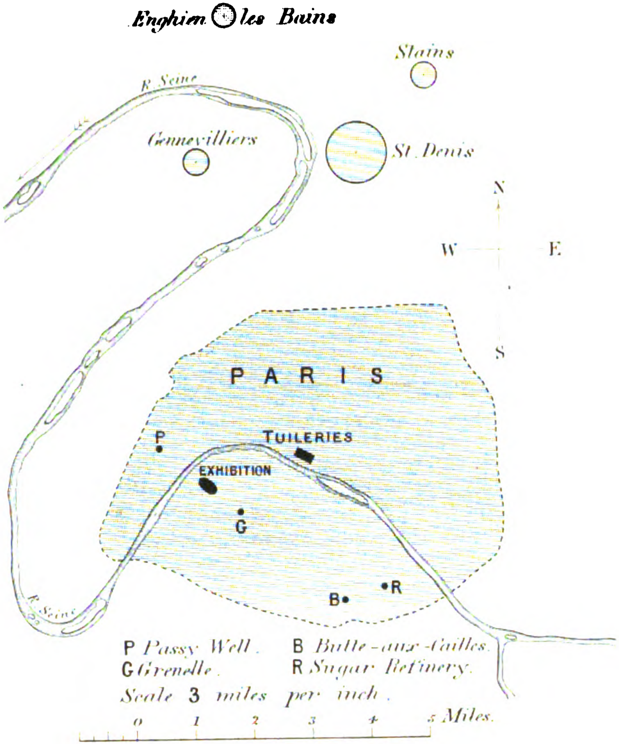


(Proceedings Inst. M.E. 1867. Page 174.)

Scale 80 miles per inch.

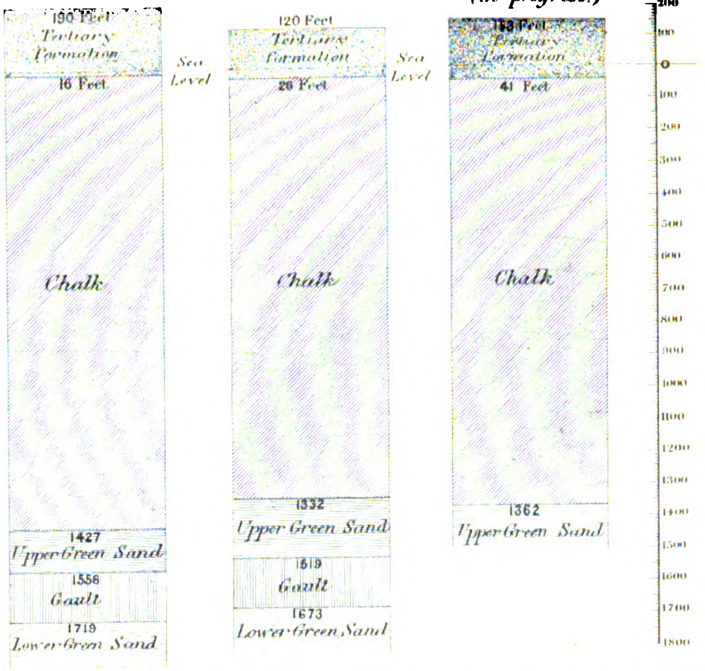
BORING ARTESIAN WELLS.

Fig. 36. Plan showing situation of Artesian Wells in Paris and neighbourhood.



Sections of Strata at three Artesian Wells in Paris.

Fig. 37. Passy. Fig. 38. Grenelle. Fig. 39. Sugar Refinery. (in progress.)



(Proceedings Inst. M.E. 1867. Page 174.)

SUEZ CANAL DREDGERS.

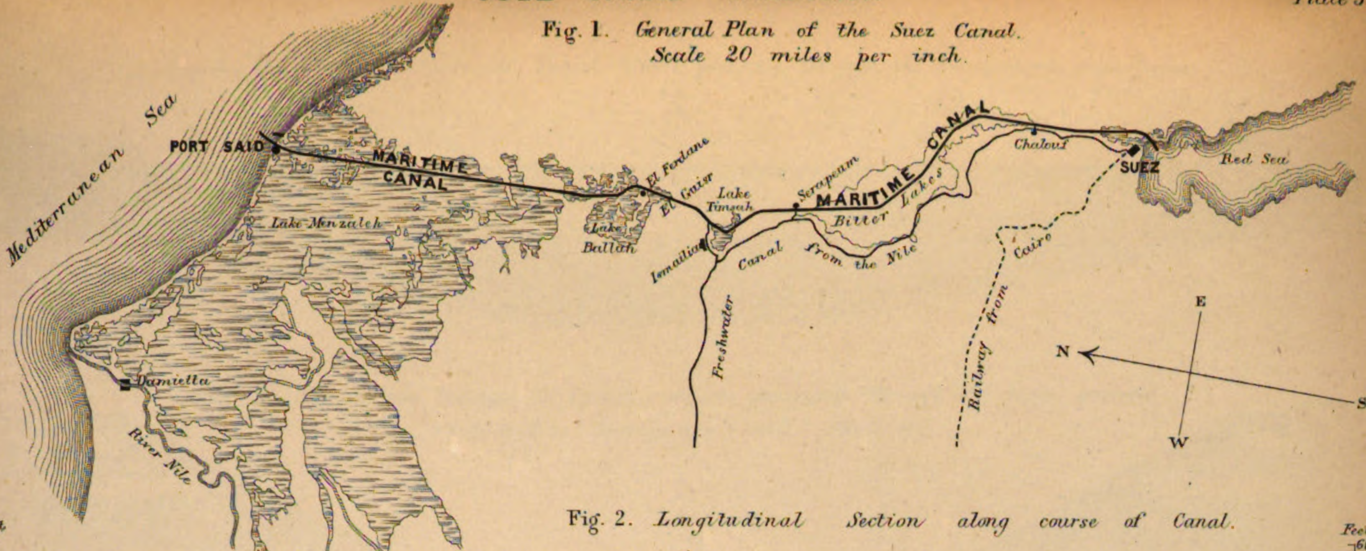


Fig. 1. *General Plan of the Suez Canal.*
Scale 20 miles per inch.

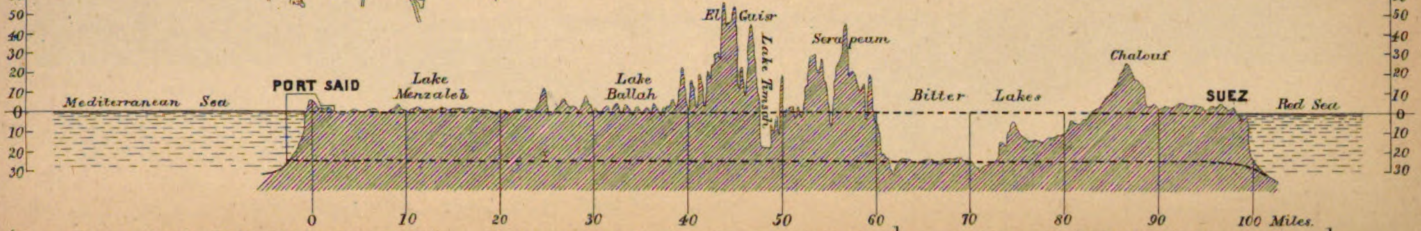


Fig. 2. *Longitudinal Section along course of Canal.*

(*Proceedings Inst. M.E. 1867. Page 192*) *Horizontal Scale* 20 *miles per inch* = $\frac{1}{1,267,000}$ *Vertical Scale* 100 *feet per inch* = $\frac{1}{1200}$

Plate 51.

SUEZ CANAL DREDGERS.

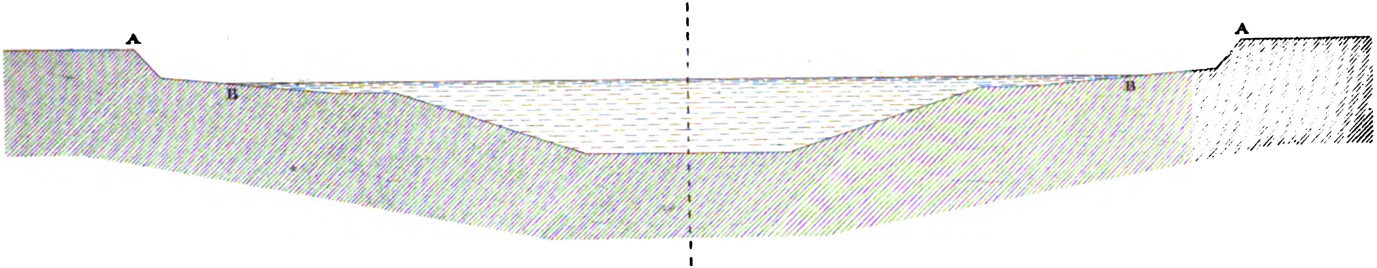
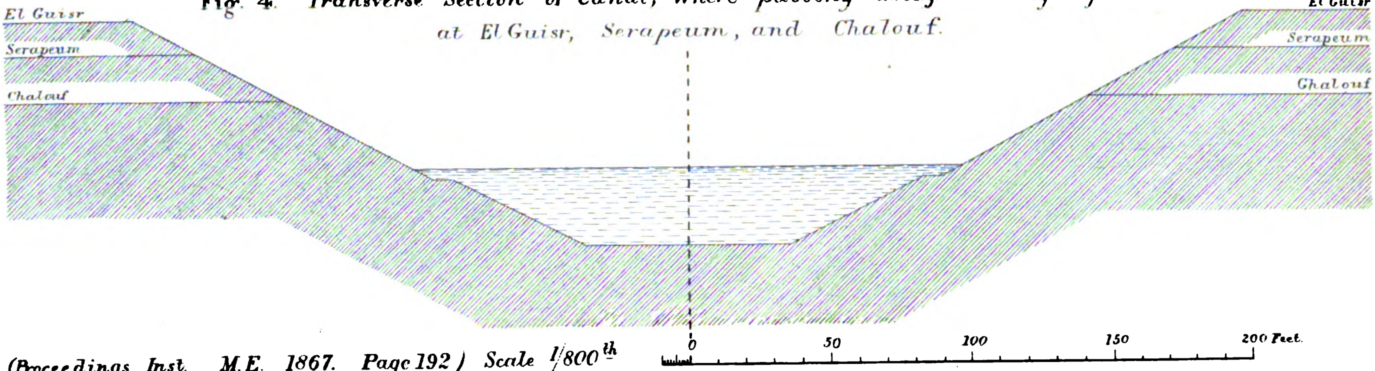


Fig. 3. Transverse Section of Canal, where passing through the low ground and lakes.

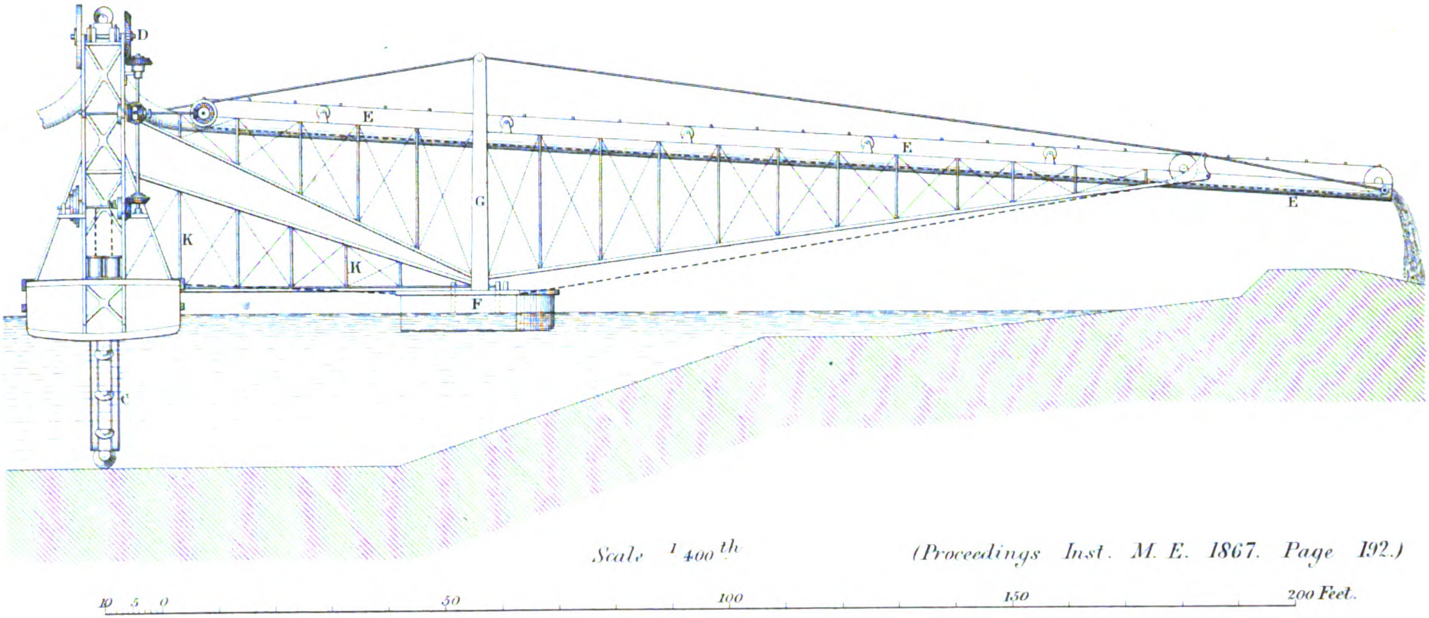
Fig. 4. Transverse Section of Canal, where passing through the high ground at El Guisr, Serapeum, and Chalouf.



(Proceedings Inst. M.E. 1867. Page 192) Scale 1/800th

SUEZ CANAL DREDGERS.

Fig. 5. *Elevation of Dredger with long shoot.*

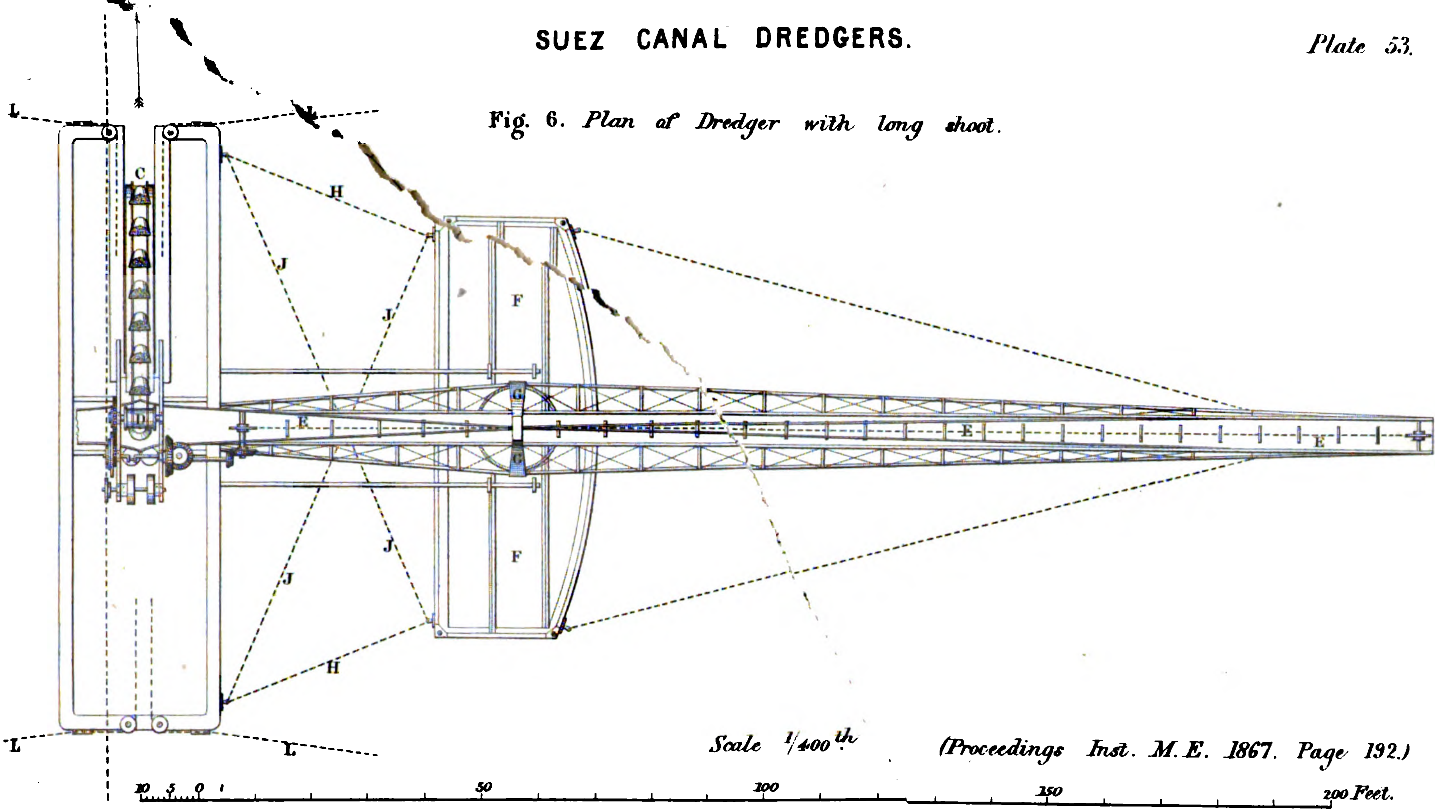


Scale $^{1}/_{400}$th

(Proceedings Inst. M. E. 1867. Page 192.)

SUEZ CANAL DREDGERS.

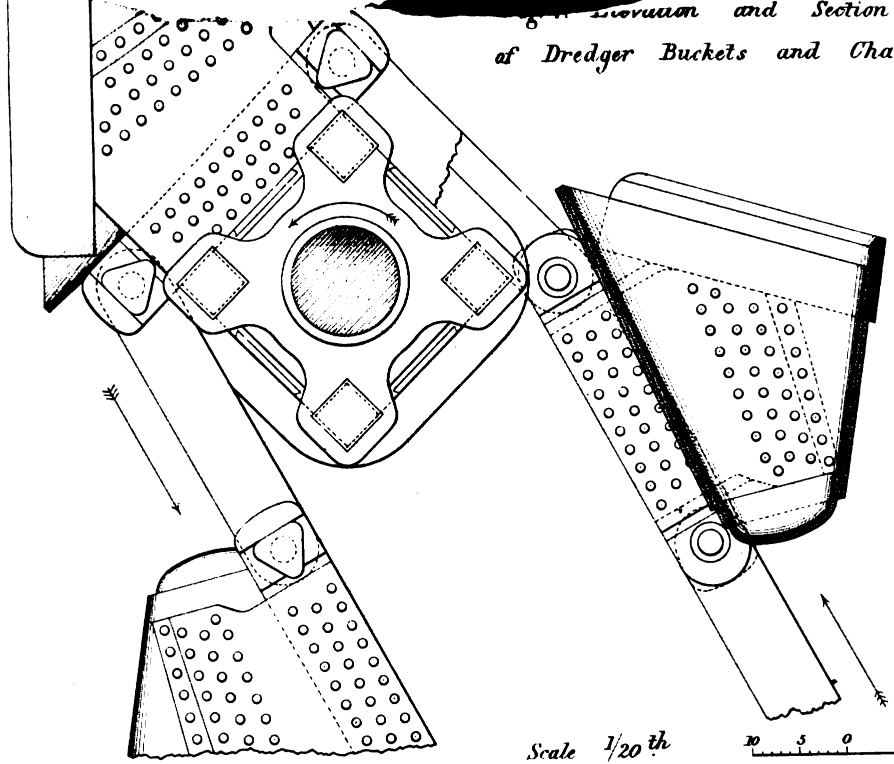
Fig. 6. *Plan of Dredger with long shoot.*



Scale 1/400th.

(Proceedings Inst. M.E. 1867. Page 192.)

Elevation and Section of Dredger Buckets and Chain.



Section at mouth of Bucket.

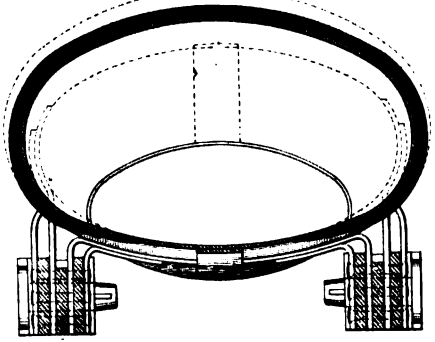


Fig. 9. Plan of Chain.

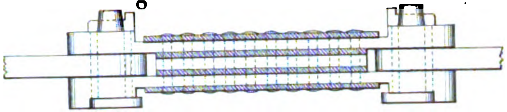


Fig. 10. Pin of Chain.

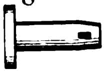
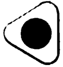
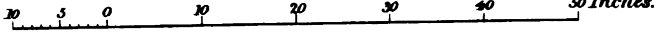


Fig. 11.



(Proceedings Inst. M. E. 1867. Page 192.)

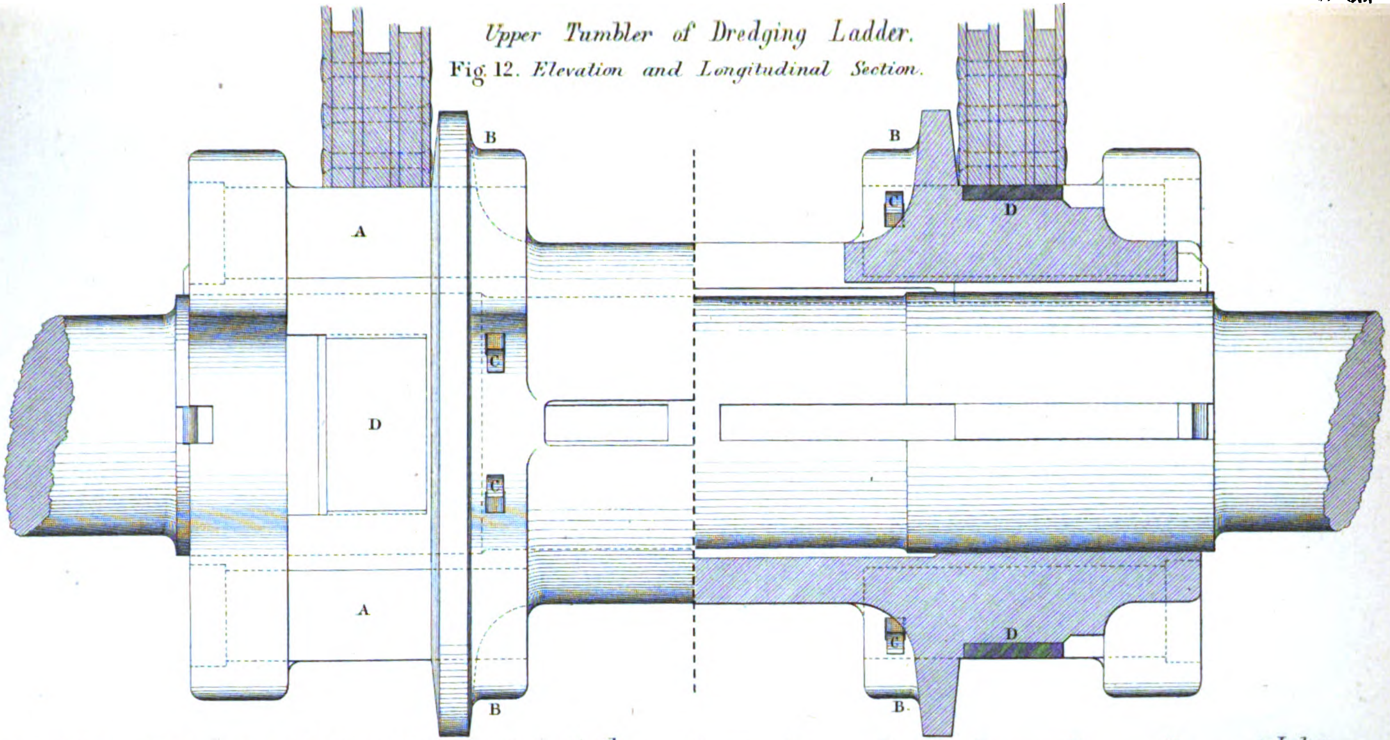
Scale 1/20th



SUEZ CANAL DREDGERS.

Upper Tumbler of Dredging Ladder.

Fig. 12. *Elevation and Longitudinal Section.*



(Proceedings Inst. M. E. 1867. Page 192.) *Scale 1/10 th*

SUEZ CANAL DREDGERS.

Upper Tumbler of Dredging Ladder.

Fig. 13. *Elevation and Transverse Section at end.*

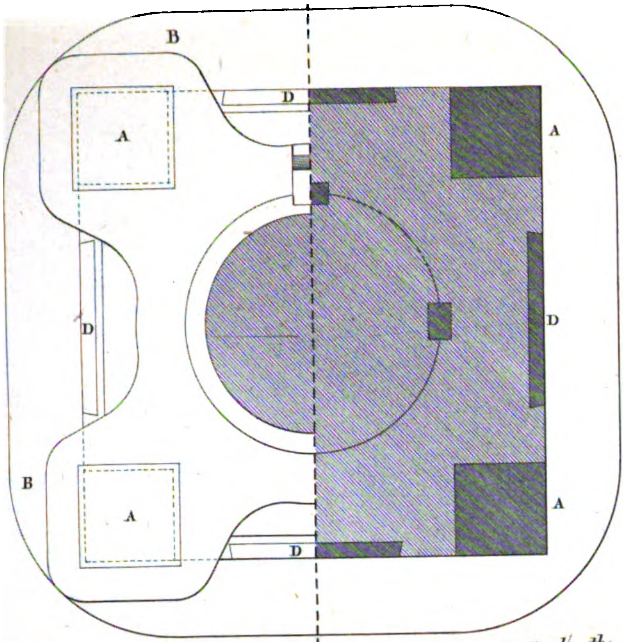
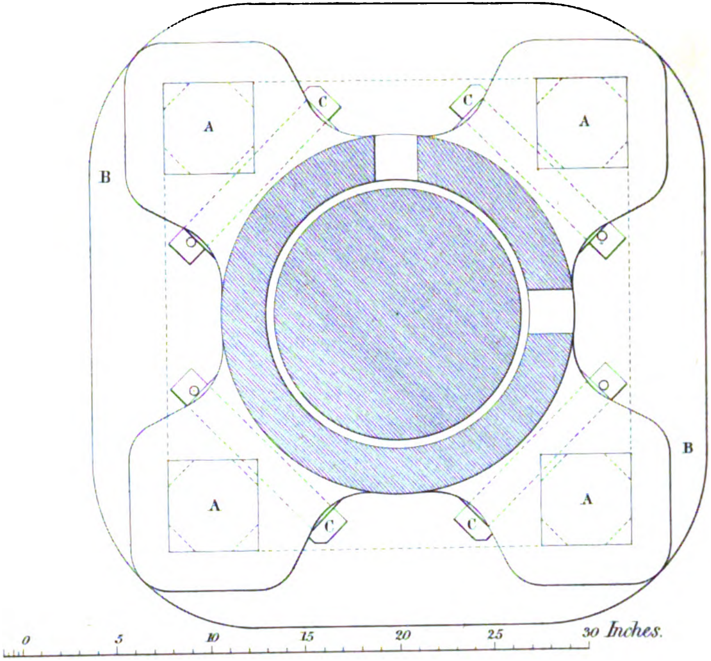


Fig. 14. *Transverse Section at centre.*

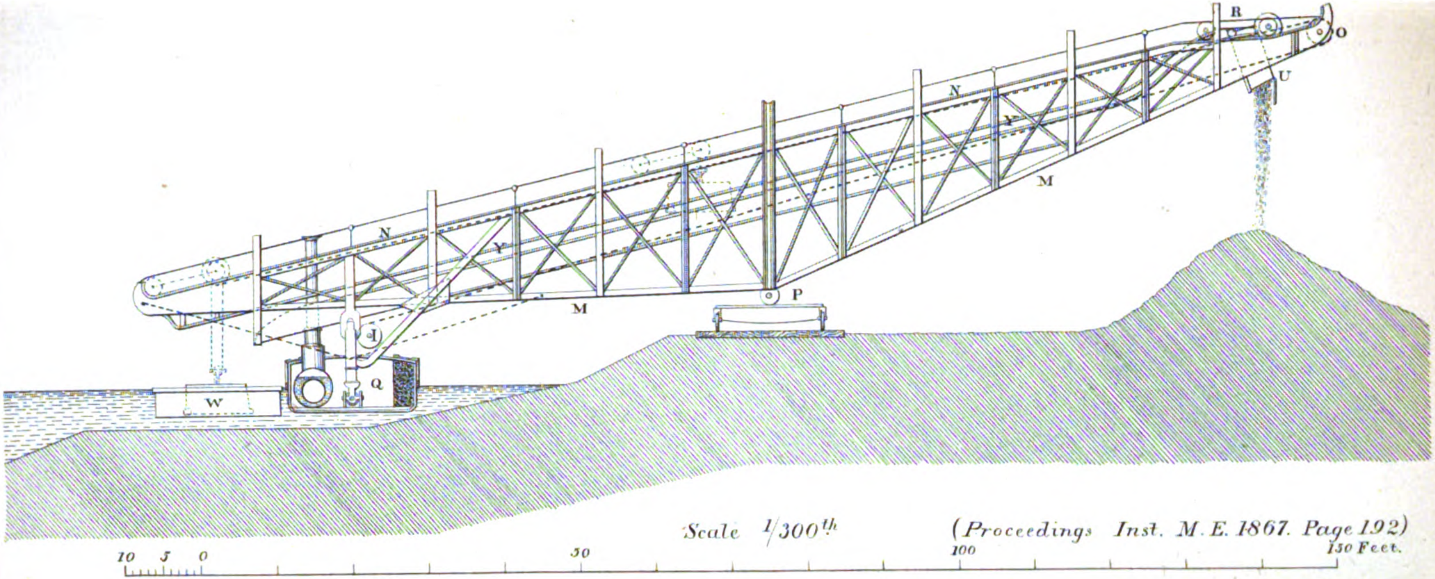


(Proceedings Inst. M. E. 1867. Page 192.)

Scale 1/10 th.

SUEZ CANAL DREDGERS.

Fig. 15. *Elevator for discharging ballast boxes.*



Scale 1/300th

(Proceedings Inst. M. E. 1867. Page 192)

SUEZ CANAL DREDGERS.

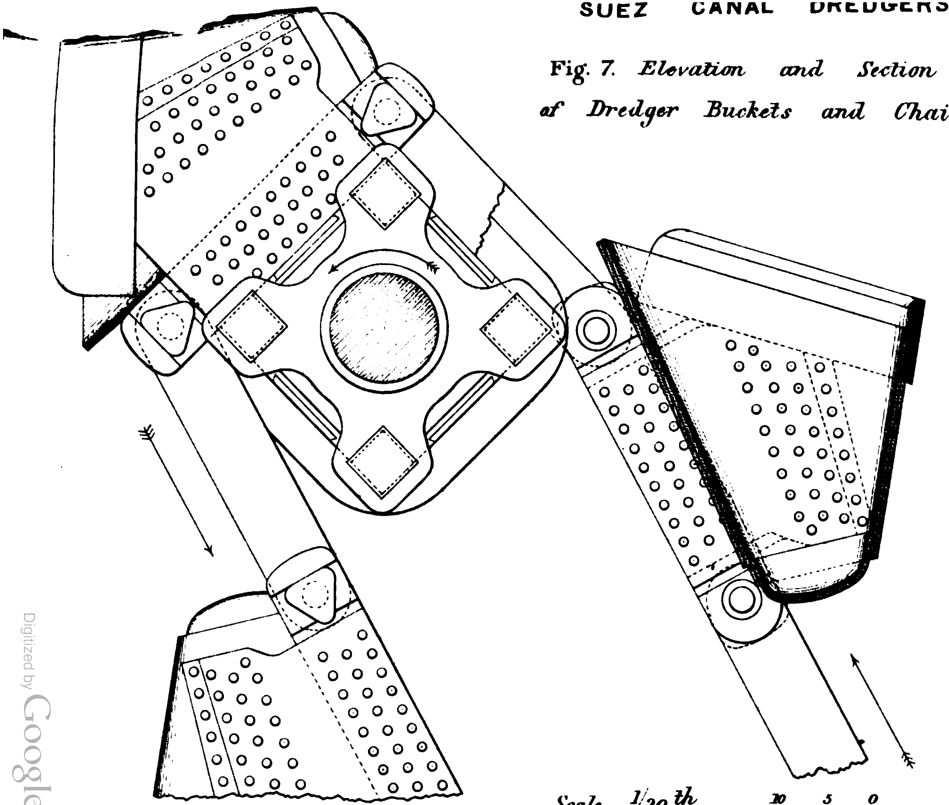


Fig. 7. Elevation and Section of Dredger Buckets and Chain.

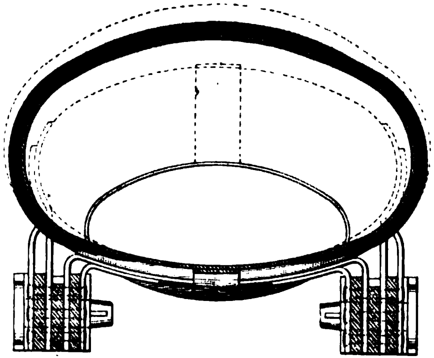


Fig. 8. Transverse Section at mouth of Bucket.

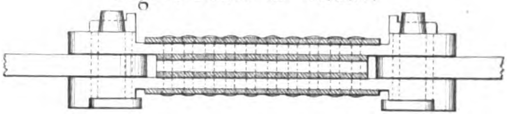


Fig. 9. Plan of Chain.

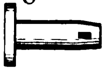


Fig. 10. Pin of Chain.

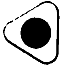
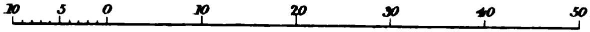


Fig. 11.

(Proceedings Inst. M. E. 1867. Page 192.)

Scale 1/20th

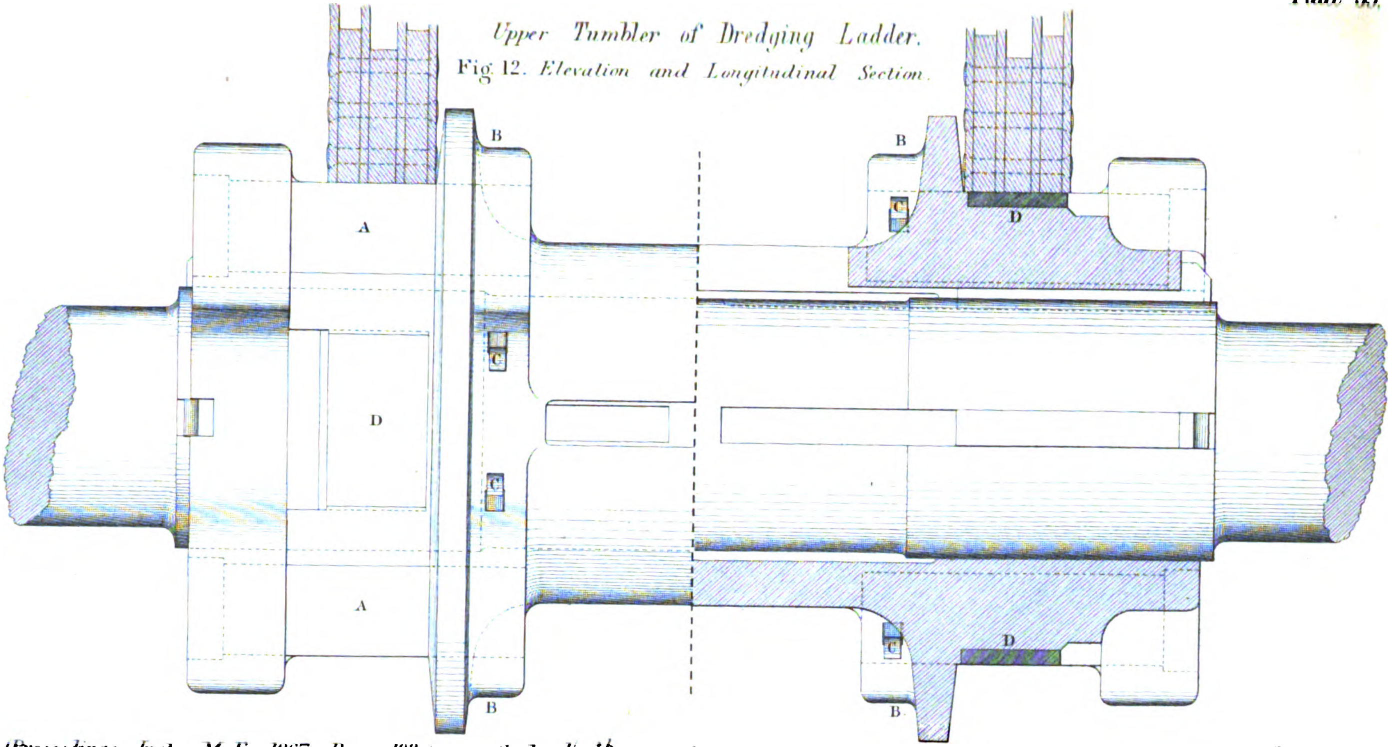


Inches.

SUEZ CANAL DREDGERS.

Upper Tumbler of Dredging Ladder.

Fig. 12. *Elevation and Longitudinal Section.*



(Proceedings Inst. M. E. 1867. Page 192.) *Scale 1/10 th*

0 5 10 15 20 25 30 *Inches.*

SUEZ CANAL DREDGERS.

Upper Tumbler of Dredging Ladder.

Fig. 13. *Elevation and Transverse Section at end.*

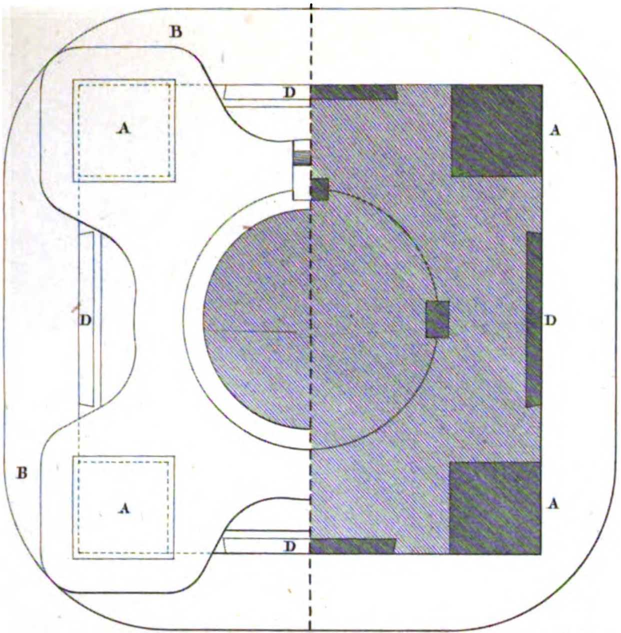
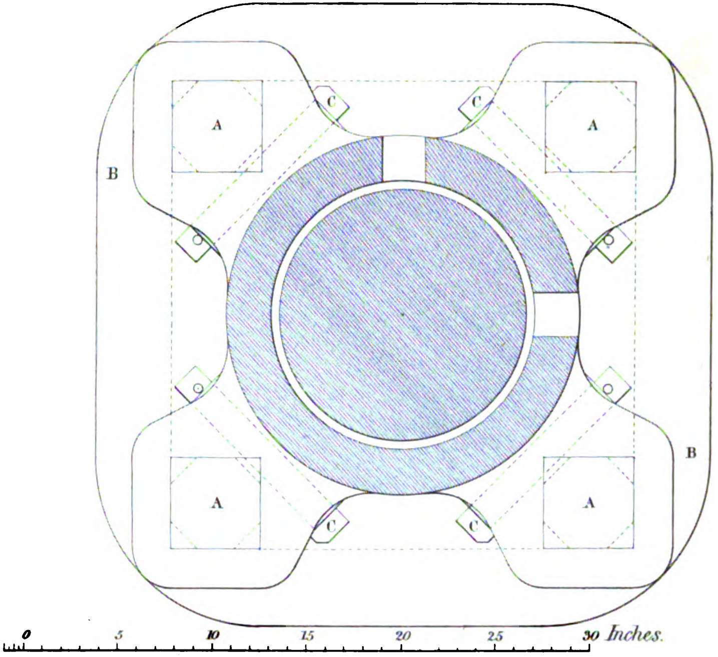


Fig. 14. *Transverse Section at centre.*

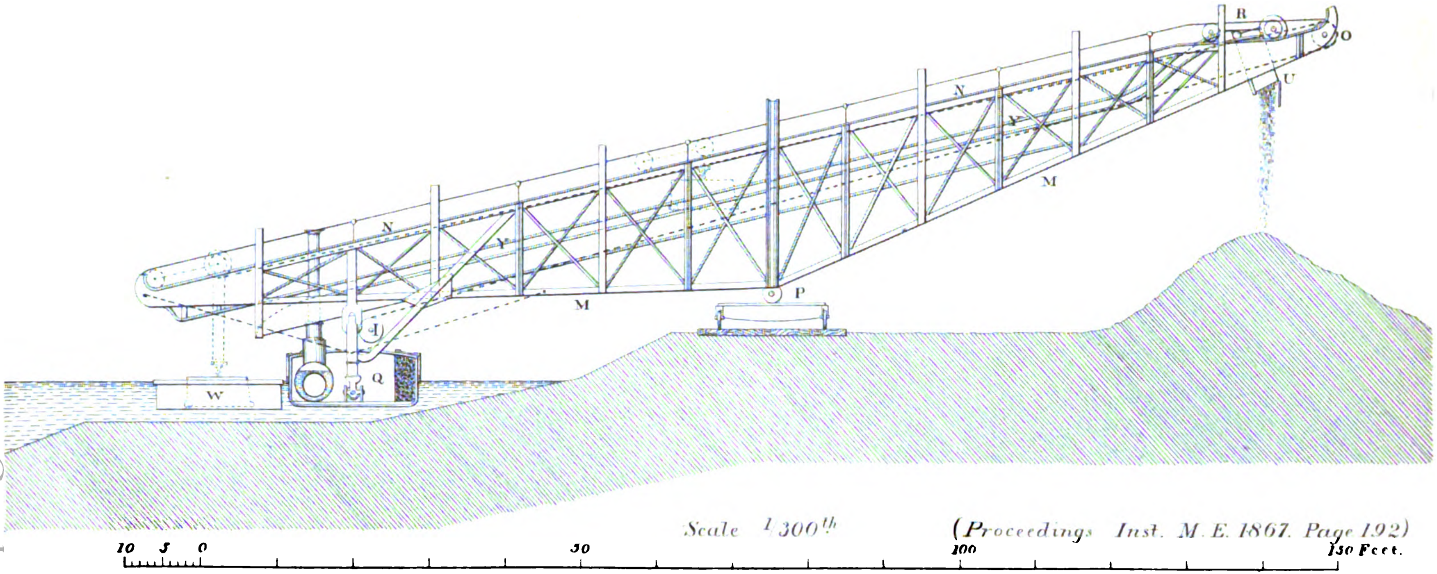


(Proceedings Inst. M. E. 1867. Page 192.) *Scale 1/10 th.*

SUEZ CANAL DREDGERS.

Plate 57.

Fig. 15. *Elevator for discharging ballast boxes.*



Scale 1/300th

(Proceedings Inst. M. E. 1867. Page 192)

SUEZ CANAL DREDGERS.

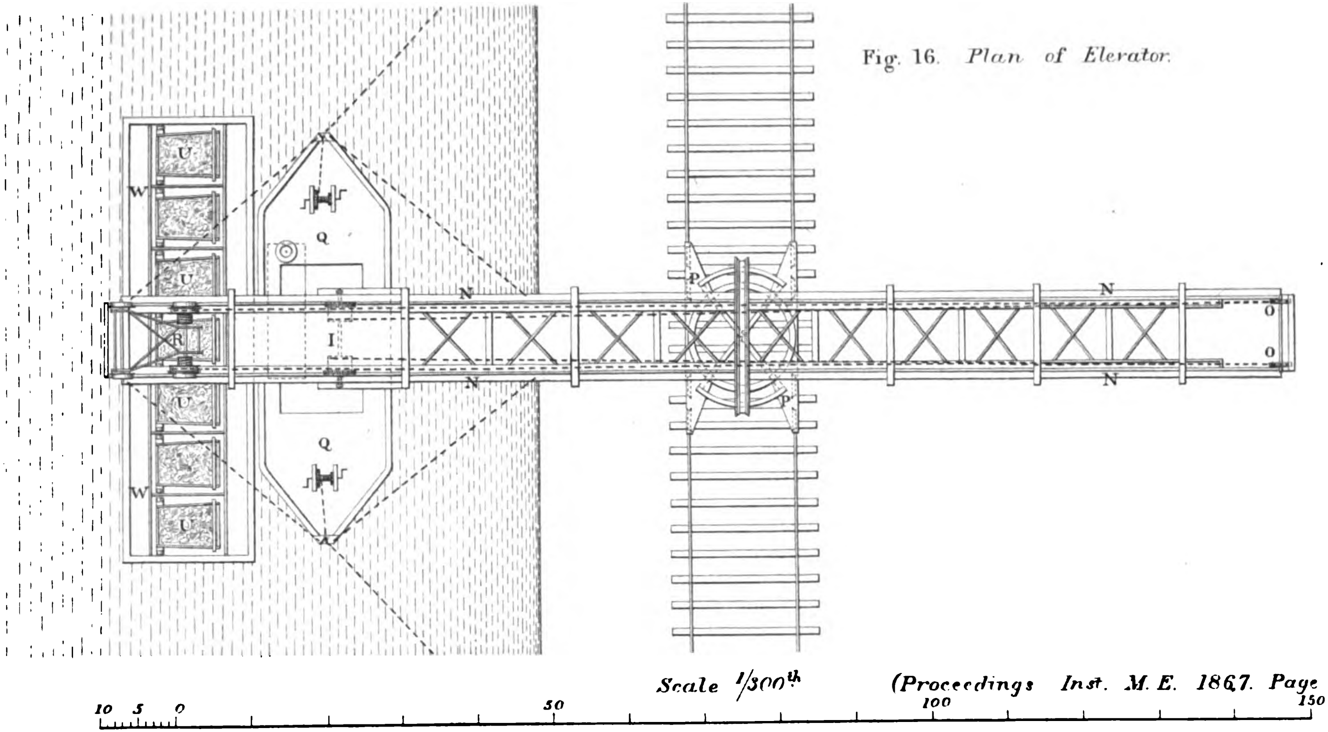


Fig. 16. *Plan of Elevator.*

Scale 1/300th

(Proceedings Inst. M. E. 1867. Page 192)

SUEZ CANAL DREDGERS.

Plate 59.

Trolly for carrying ballast boxes on Elevator.

Fig. 17. *Longitudinal Section.*

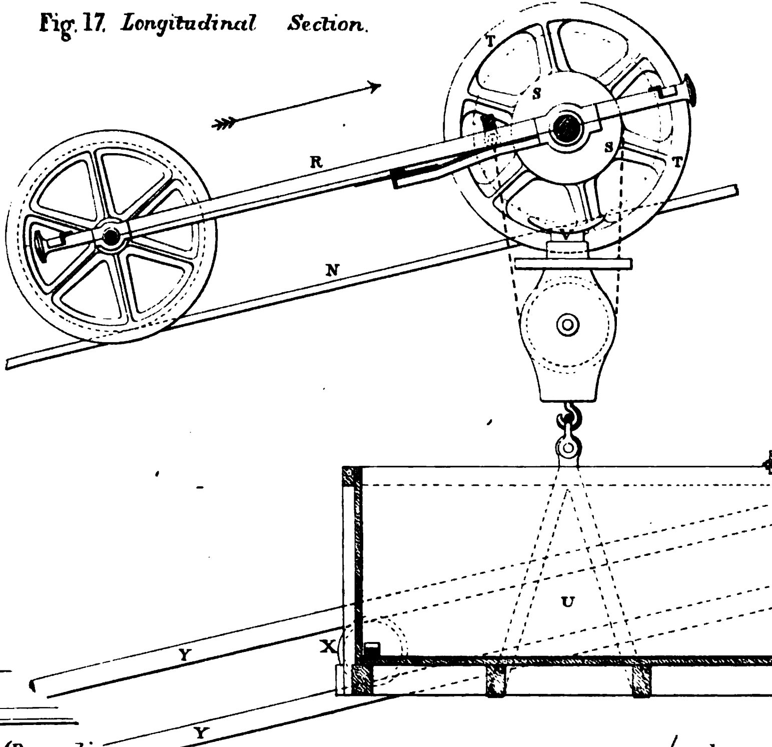
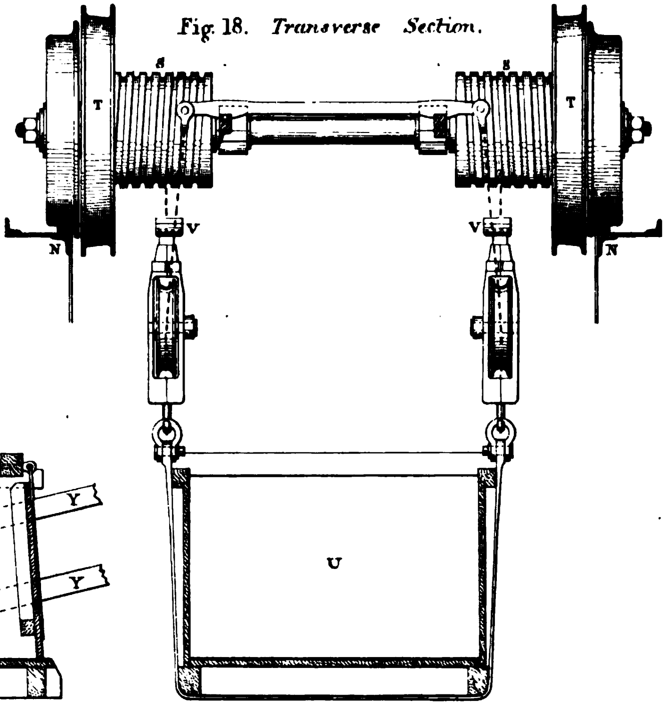
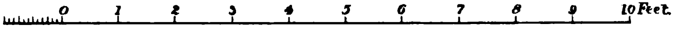


Fig. 18. *Transverse Section.*



(Proceedin.

(Proceedings Inst. M.E. 1867. Page 192) Scale $1/40^{th}$.



SUEZ CANAL DREDGERS.

Fig. 19. *Plan of Trolly for carrying ballast boxes on Elevator.*

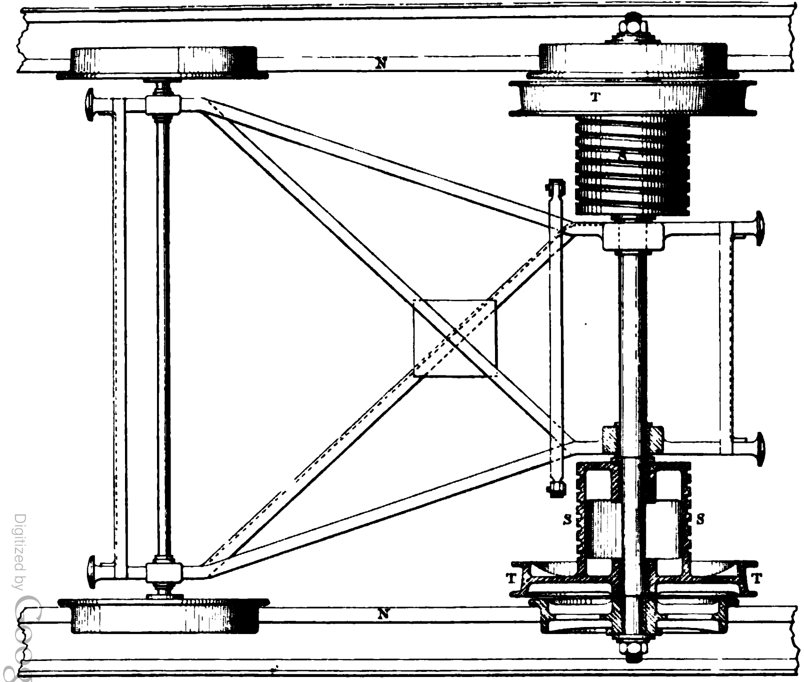
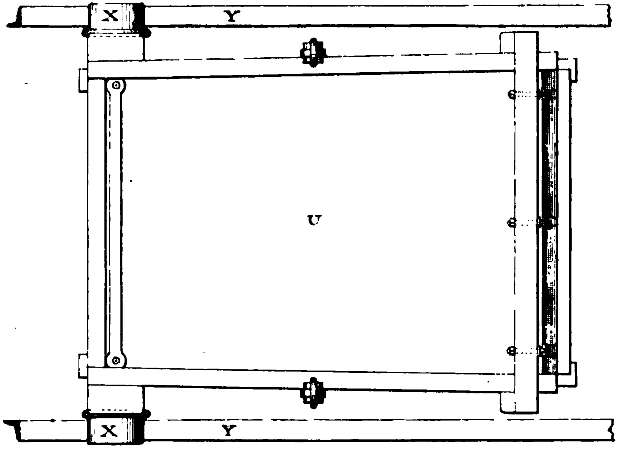
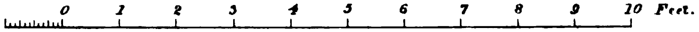


Fig. 20. *Plan of Ballast Box.*



(Proceedings Inst. M.E. 1867. Page 192) *Scale 1/40th*



SUEZ CANAL DREDGERS.

Ballast Lighter with Bottom Doors for discharging in the lakes.

Fig. 21. Longitudinal Section.

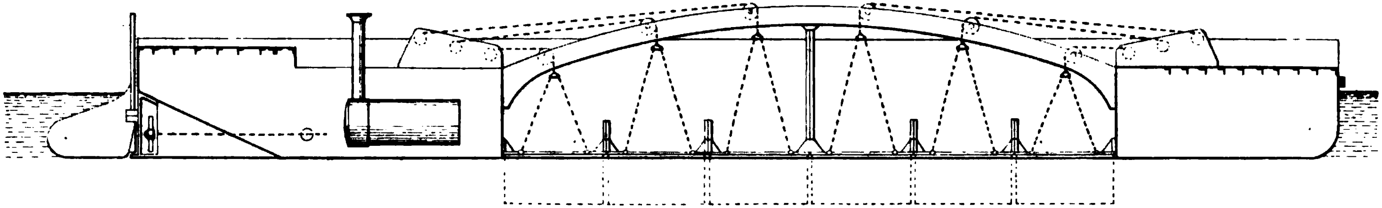
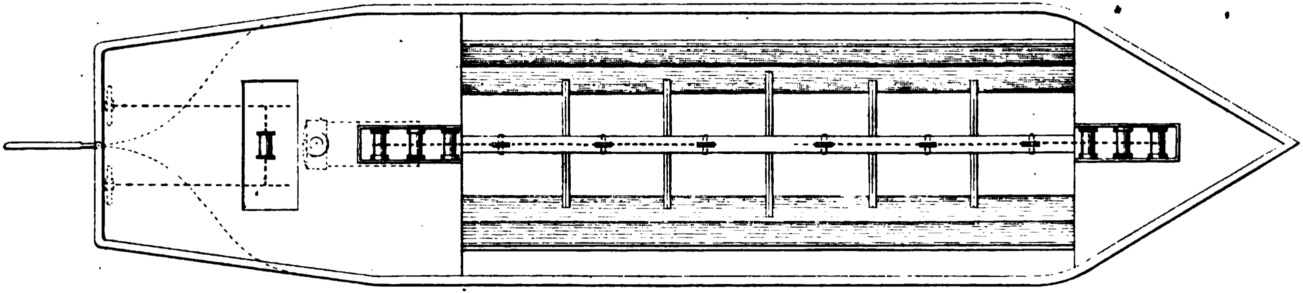
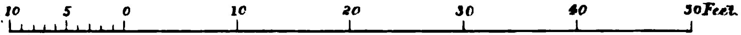


Fig. 22. Plan.



(Proceedings Inst. M.E. 1867. Page 192)

Scale 1/200th



SUEZ CANAL DREDGERS.

Ballast Lighter with Side Doors for discharging in shallow water.

Fig. 23. Longitudinal Section.

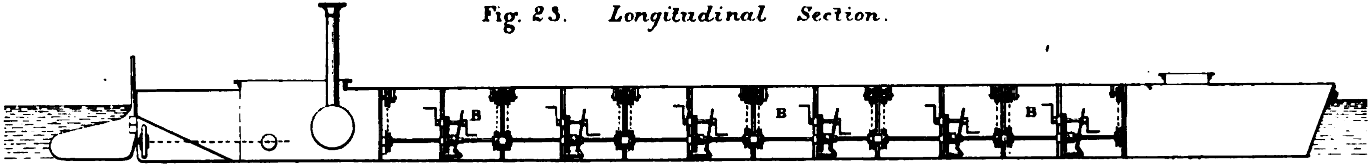
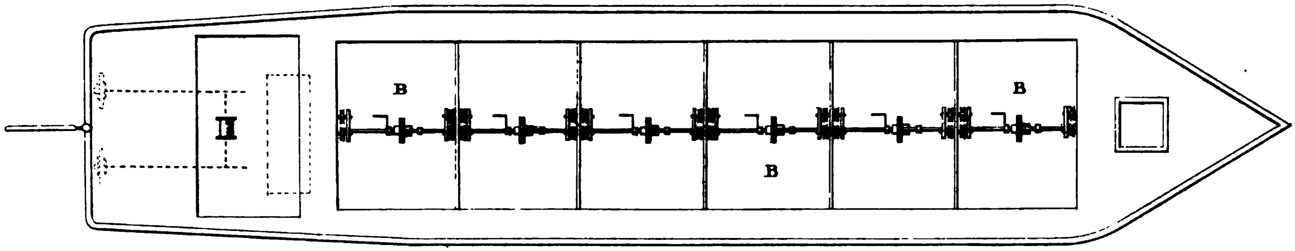


Fig. 24. Plan.



(Proceedings Inst. M.E. 1867. Page 192)

Scale 1/200th 10 5 0 10 20 30 40 50 Feet

Fig. 25. Transverse Section of Sea-going Ballast Lighter with Bottom Doors.

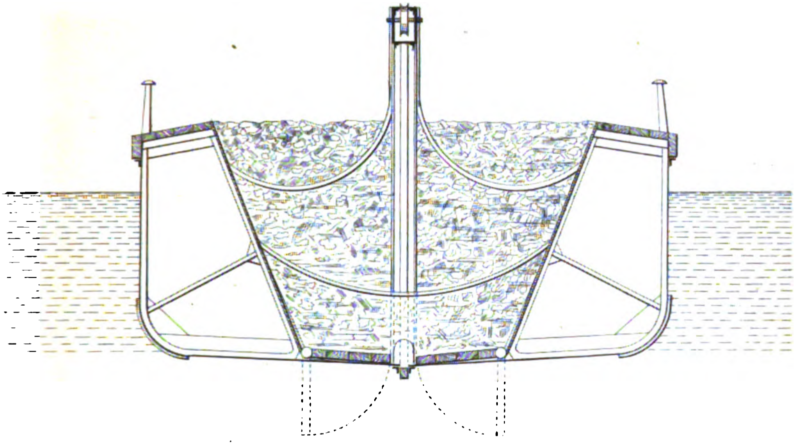


Fig. 26. Transverse Section of Ballast Lighter with Bottom Doors for discharging in the lakes.

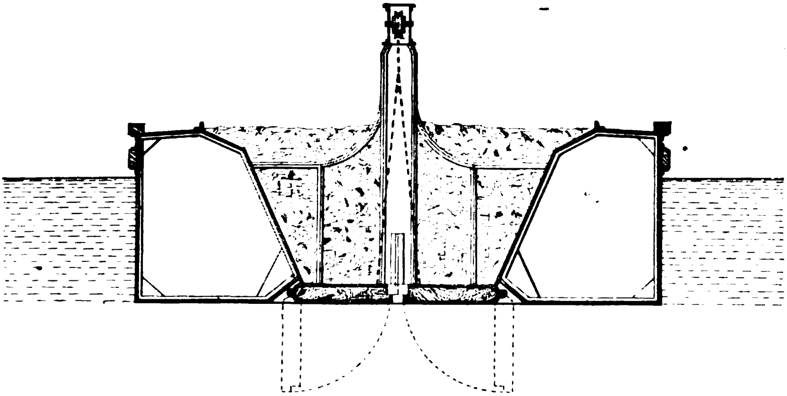
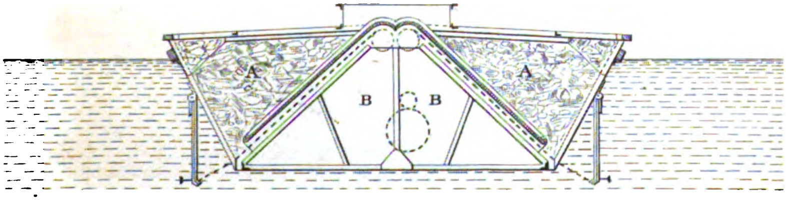


Fig. 27. Transverse Section of Ballast Lighter with Side Doors for discharging in shallow water.



(Proceedings Inst. M.E. 1867. Page 192) Scale 1/100th

10 5 0 10 20 Feet

SUEZ CANAL DREDGERS. Plate 63

Fig. 25. Transverse Section of Sea-going Ballast Lighter with Bottom Doors.

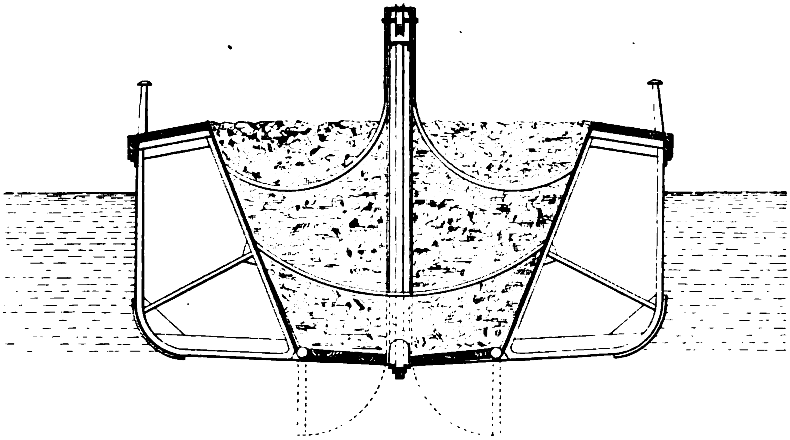


Fig. 26. Transverse Section of Ballast Lighter with Bottom Doors for discharging in the lakes.

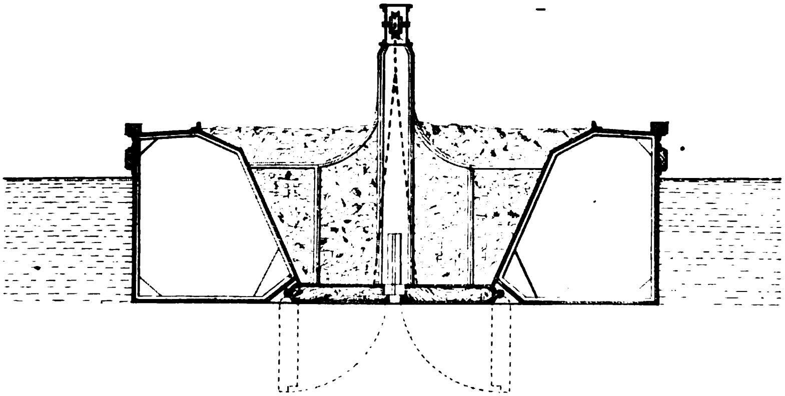
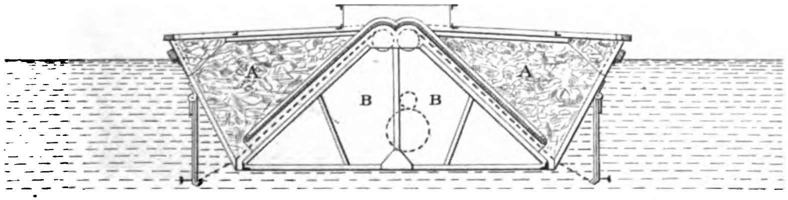


Fig. 27. Transverse Section of Ballast Lighter with Side Doors for discharging in shallow water.



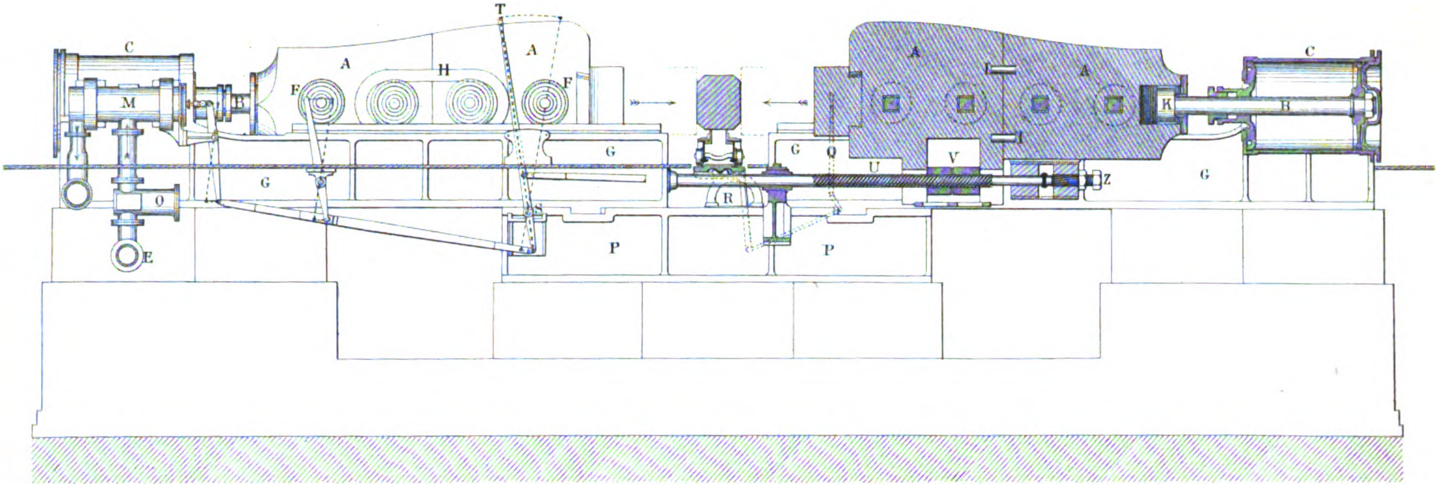
(Proceedings Inst. M.E. 1867. Page 192) Scale 1/100th

10 5 0 10 20 Feet

HORIZONTAL DUPLEX HAMMER.

Plate 64.

Fig. 1. *Side Elevation and Longitudinal Section of* 30 *ton Horizontal Duplex Hammer.*



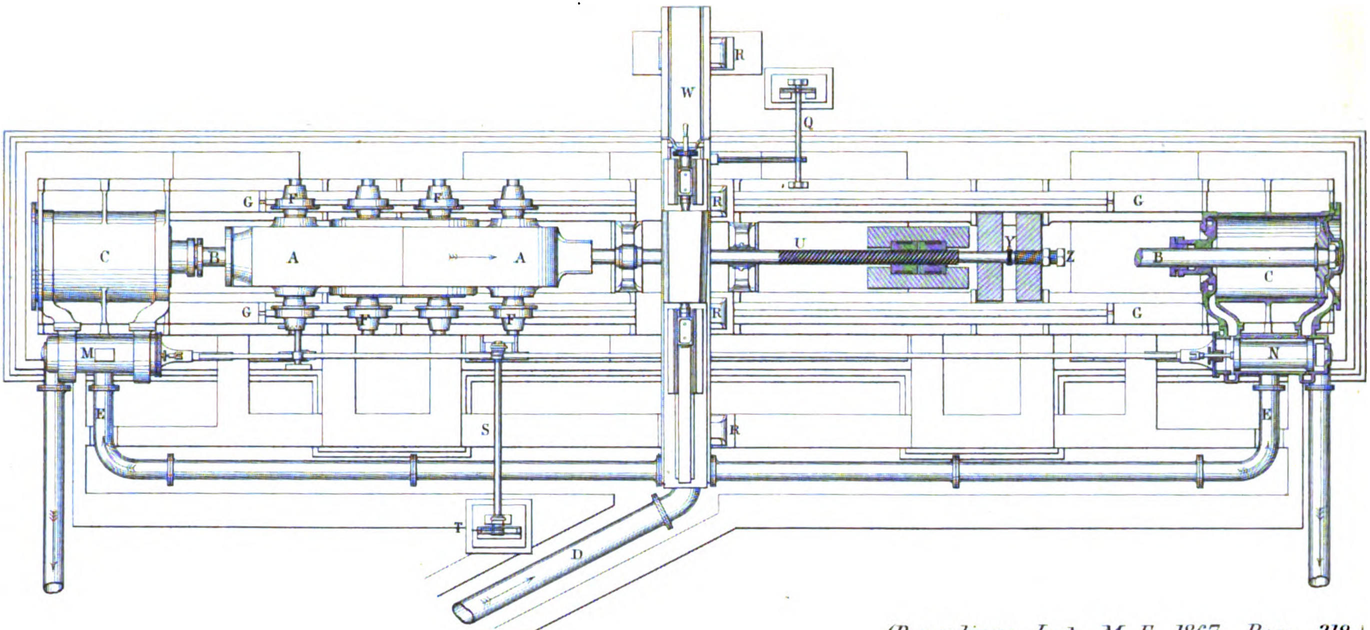
(Proceedings Inst. M. E. 1867. Page 218.)

Scale 1/80 th 10 5 0 10 20 30 *Feet.*

HORIZONTAL DUPLEX HAMMER.

Plate 65.

Fig. 2. *Plan and Sectional Plan of* 30 *ton Horizontal Duplex Hammer.*



(Proceedings Inst. M. E. 1867. Page 218.)

Scale 1/80 th 10 5 0 10 20 30 *Feet.*

HORIZONTAL DUPLEX HAMMER.

Fig. 3. *Transverse Section through Hammer Tup.*

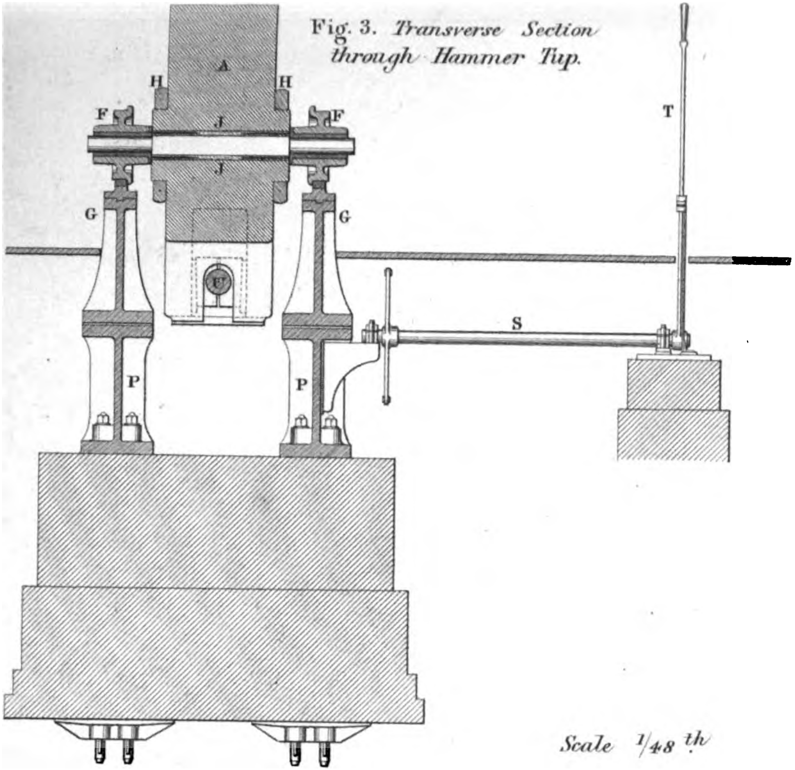
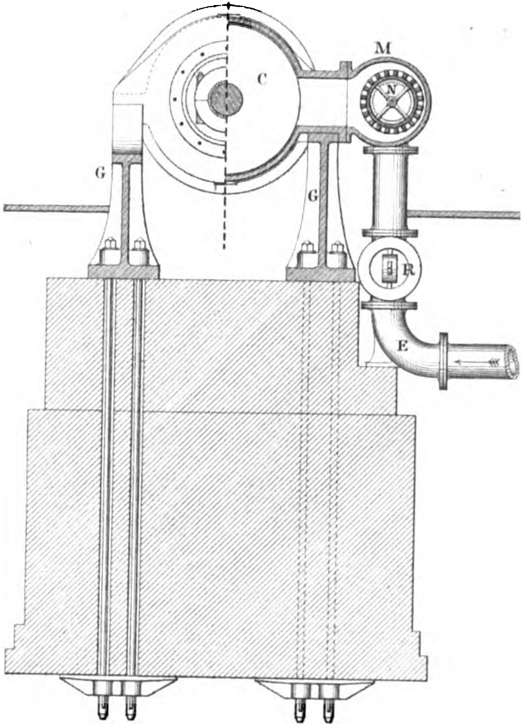
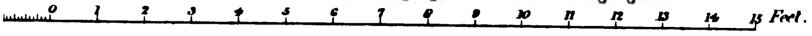


Fig. 4. *Transverse Section through Cylinder.*



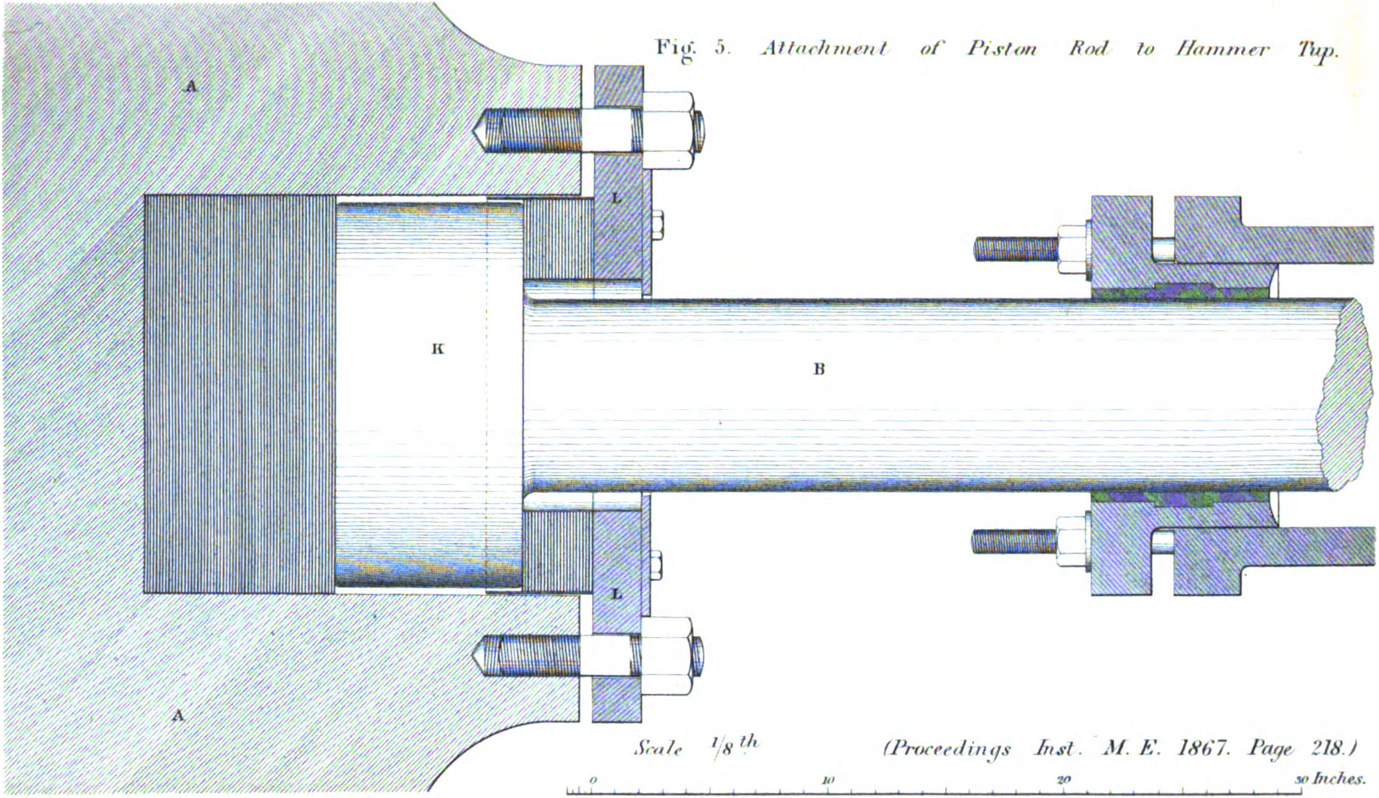
Scale 1/48th.



(Proceedings Inst. M. E. 1867. Page 218.)

HORIZONTAL DUPLEX HAMMER.

Fig. 5. Attachment of Piston Rod to Hammer Tup.



(Proceedings Inst. M. E. 1867. Page 218.)

HORIZONTAL DUPLEX HAMMER.

Valve Chest and Valve.

Fig. 6. *Longitudinal Section.*

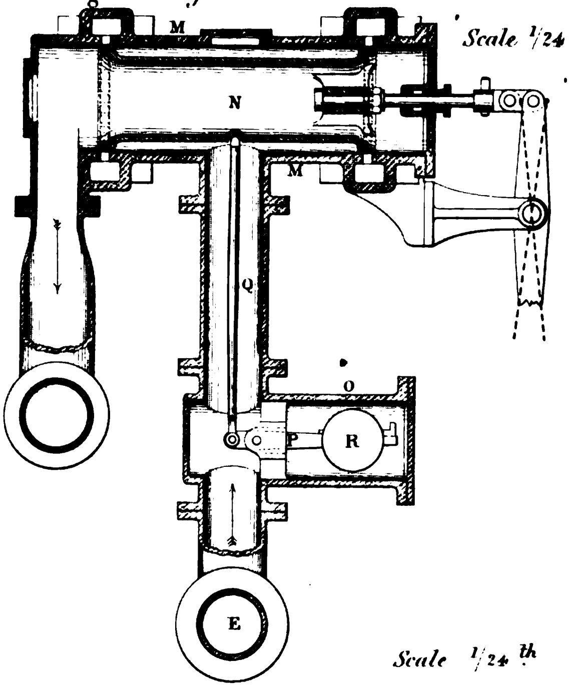


Fig. 7. *Transverse Section.*

Scale 1/24 th

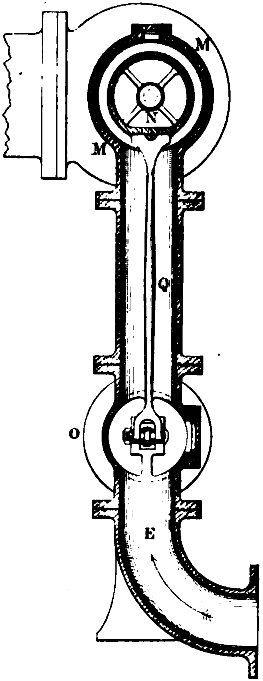
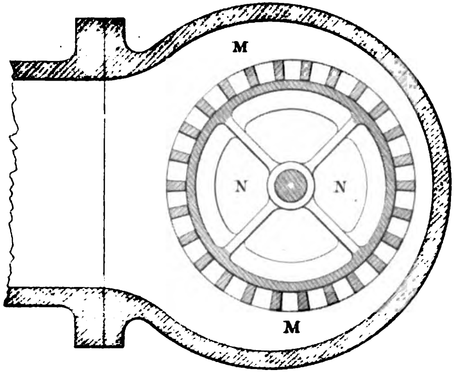


Fig. 8. *Enlarged Transverse Section through Ports.*

Scale 1/12 th



Scale 1/24 th

(Proceedings Inst. M. E. 1867. Page 218.)

HORIZONTAL DUPLEX HAMMER.

Longitudinal Screw connecting the two Hammer Tups.

Fig. 9. Longitudinal Section.

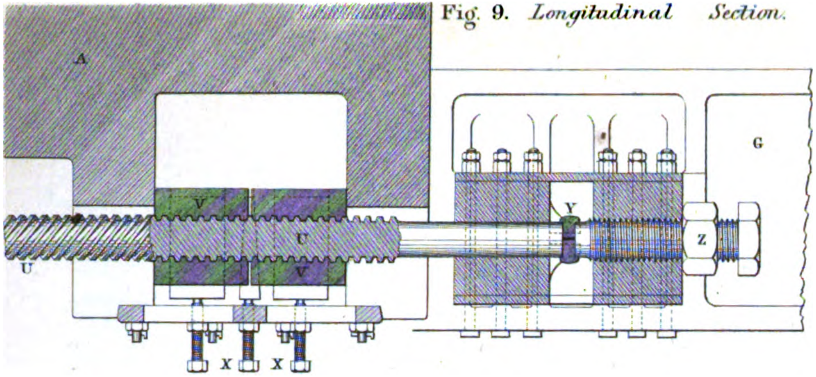


Fig. 10. Transverse Sections.

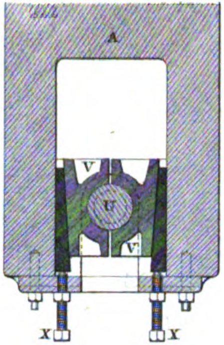


Fig. 11.

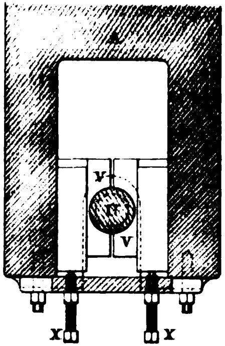


Fig. 12. Sectional Plan.

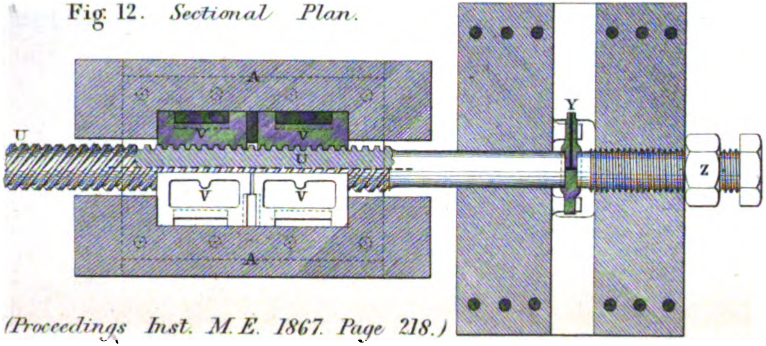
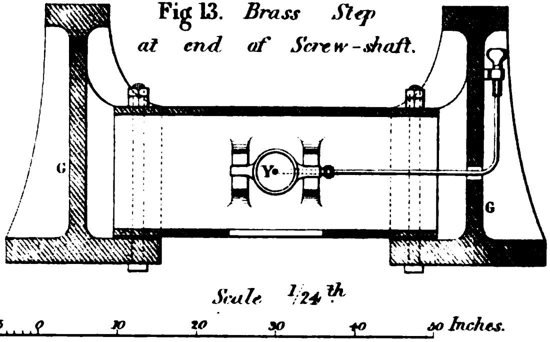


Fig 13. Brass Step at end of Screw-shaft.

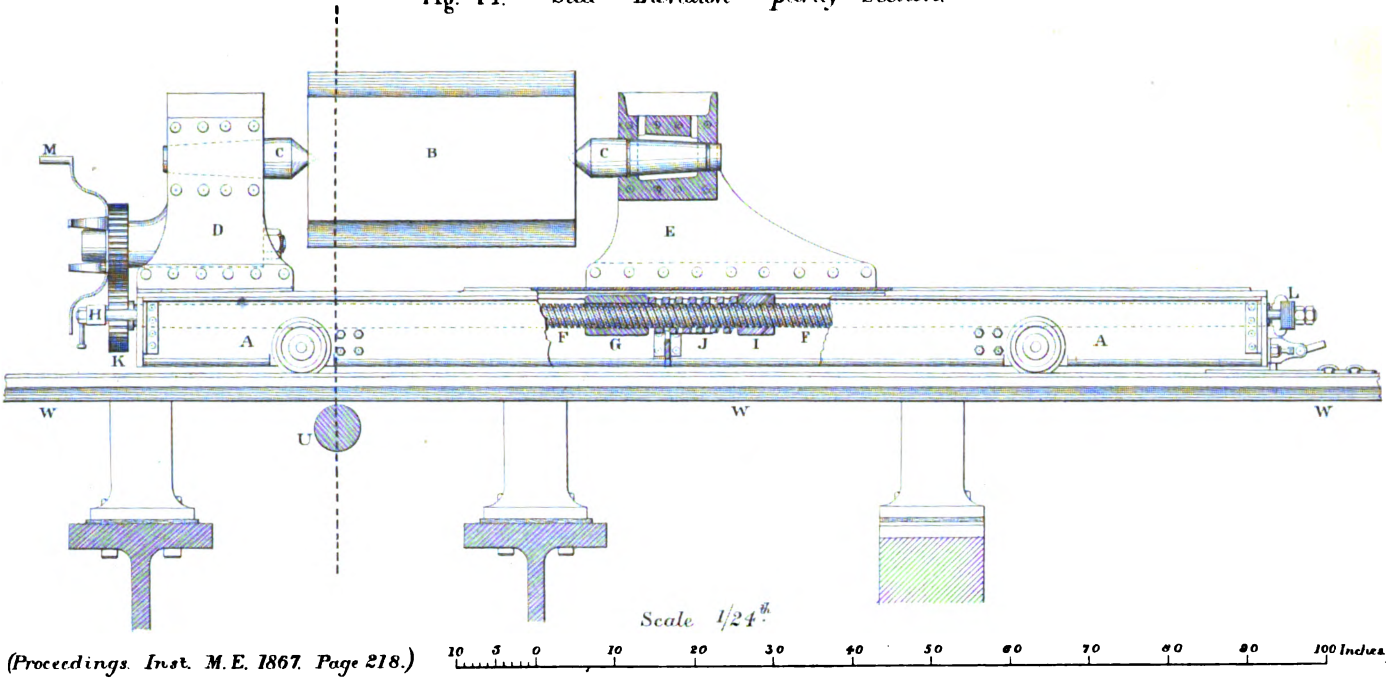


(Proceedings Inst. M.E. 1867. Page 218.)

HORIZONTAL DUPLEX HAMMER.

Truck for Ordinary Ingots.

Fig. 14. Side Elevation partly Section.

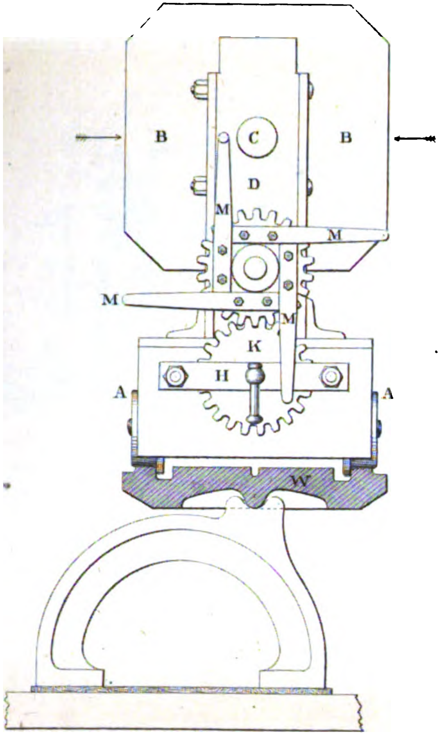


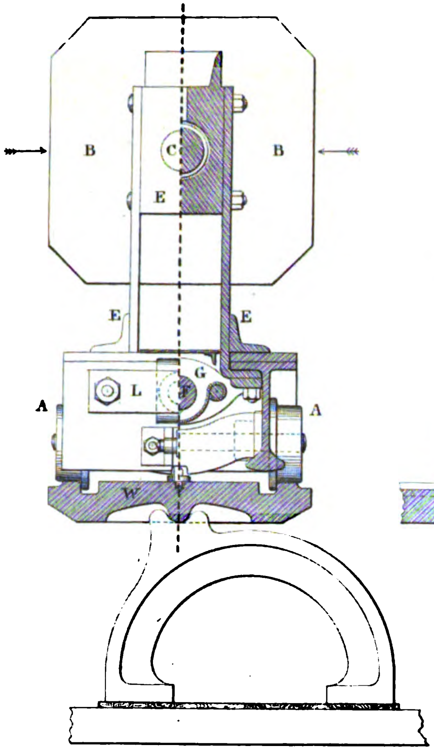
(Proceedings. Inst. M.E. 1867. Page 218.)

HORIZONTAL DUPLEX HAMMER.

Truck for Ordinary Ingots.

Fig: 15. End Elevations. Fig: 16.





Truck for Conical Ingots for weldless steel tyres.

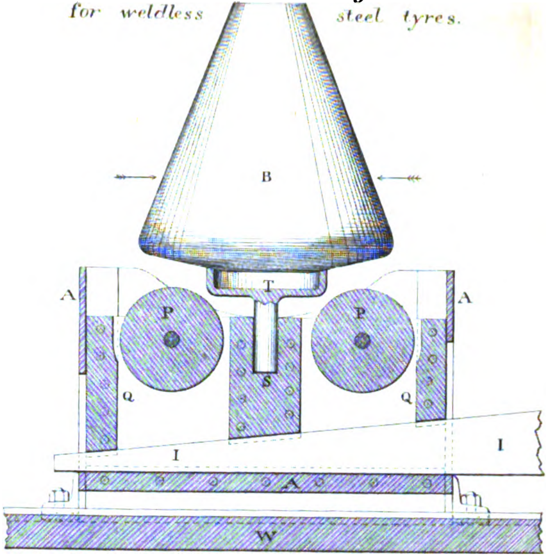


Fig: 17. Ingot in vertical position for hammering laterally.

(Proceedings Inst. M. E. 1867. Page 218.)

Scale 1/16th

0 10 20 30 Inches.

HORIZONTAL DUPLEX HAMMER.

Plate 72.

Truck for Conical Ingots for weldless steel tyres.

Ingot in horizontal position

for hammering endways.

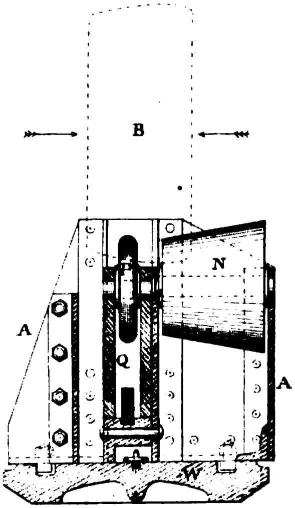


Fig. 18.
Transverse Section.

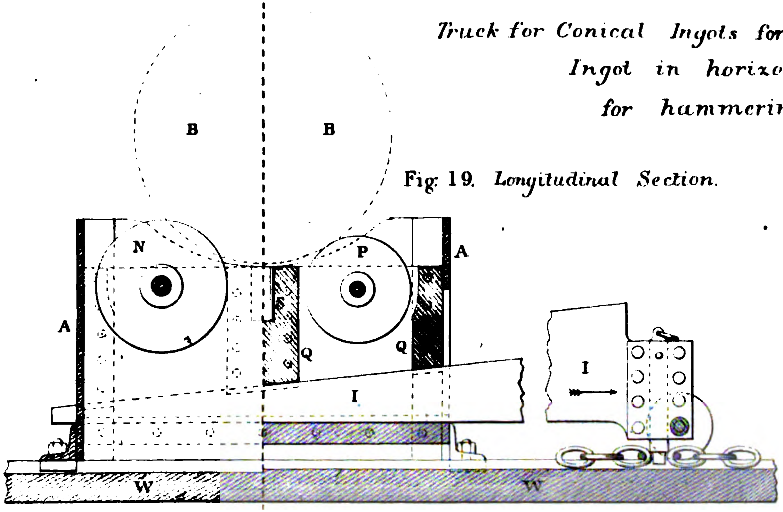


Fig. 19. *Longitudinal Section.*

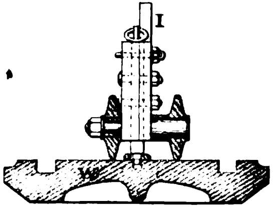


Fig. 20.
Outer end of Wedge.

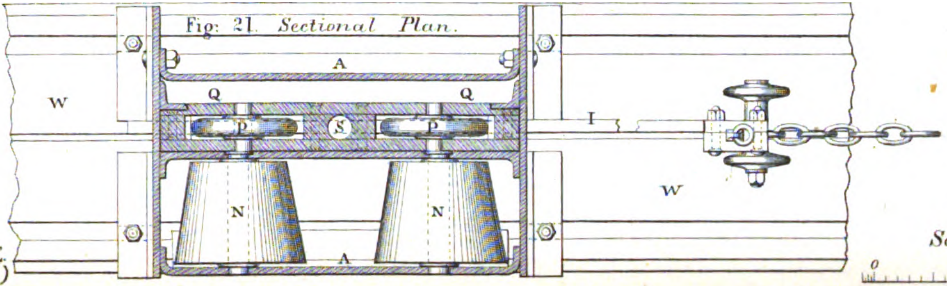


Fig. 21. *Sectional Plan.*

Scale 1/16th

0 10 20 Inches.

(*Proceedings Inst. M.E. 1867. Page 218.*)

HORIZONTAL DUPLEX HAMMER.

Truck for Bars.

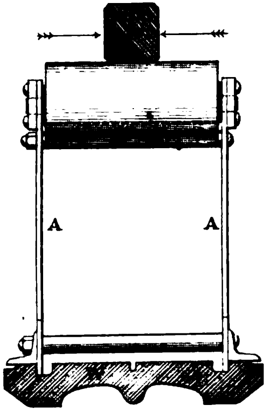


Fig. 22.
End Elevation.

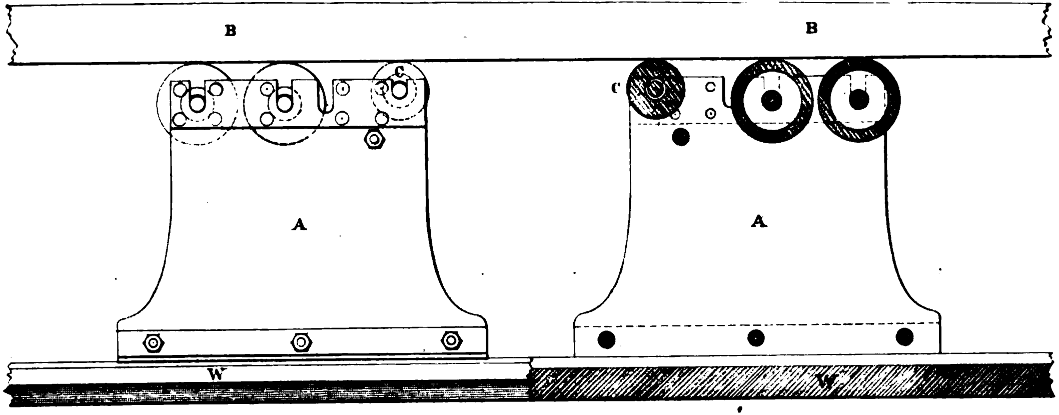


Fig. 23. *Side Elevation and Section.*

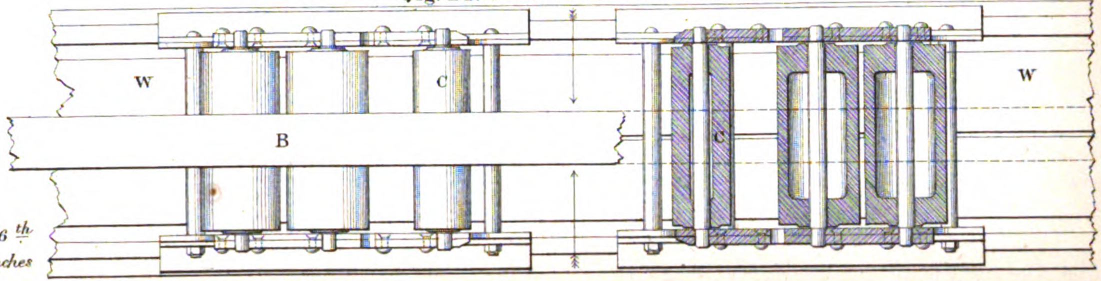


Fig. 24. *Plan and Sectional Plan.*

(Proceedings Inst. M.E. 1867. Page 218.) Scale 1/16th

0 10 20 Inches

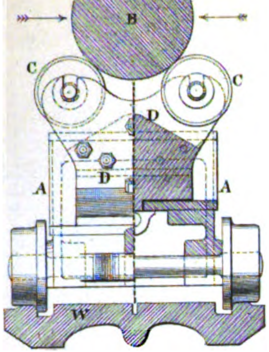
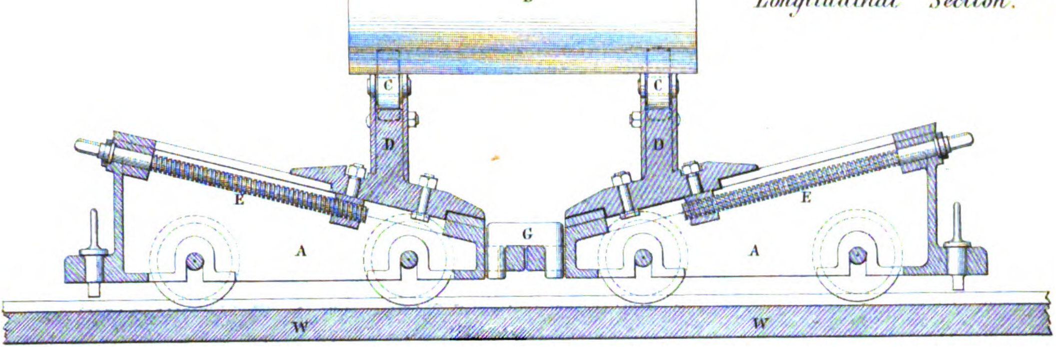
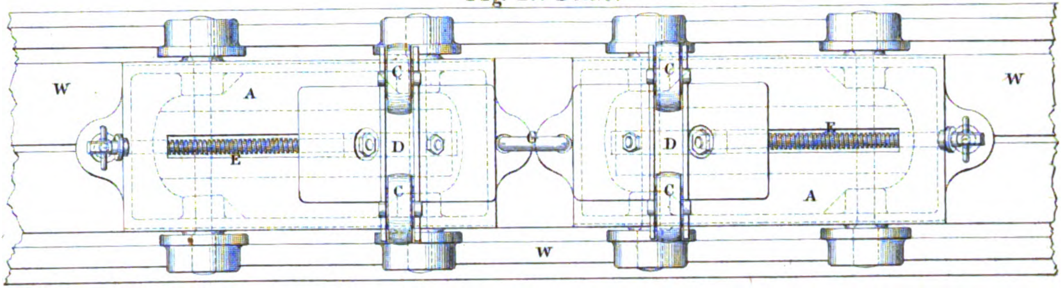


Fig. 25.
End Elevation.



Longitudinal Section.

Fig. 27. *Plan.*



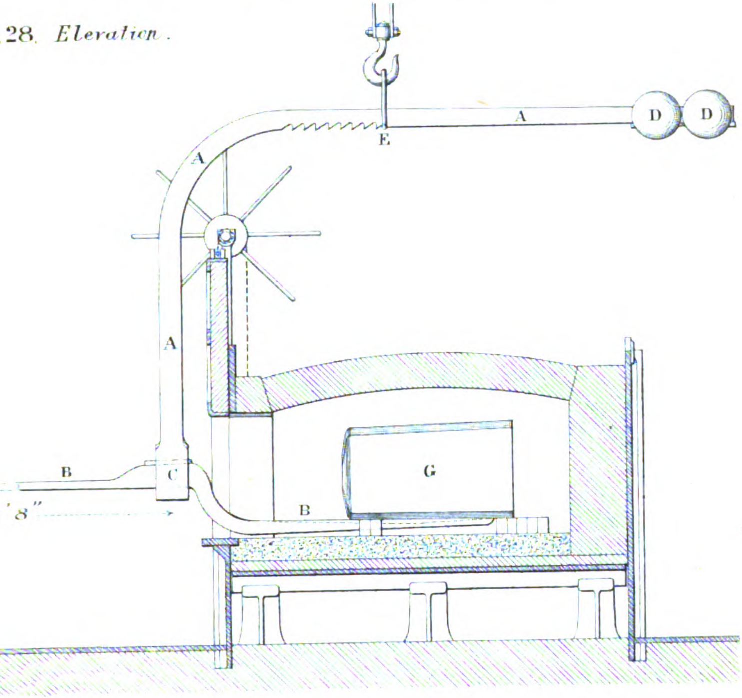
(Proceedings Inst. M. E.
1867. Page 218.) Scale 1/16th.
0 10 20 Inches.

HORIZONTAL DUPLEX HAMMER.

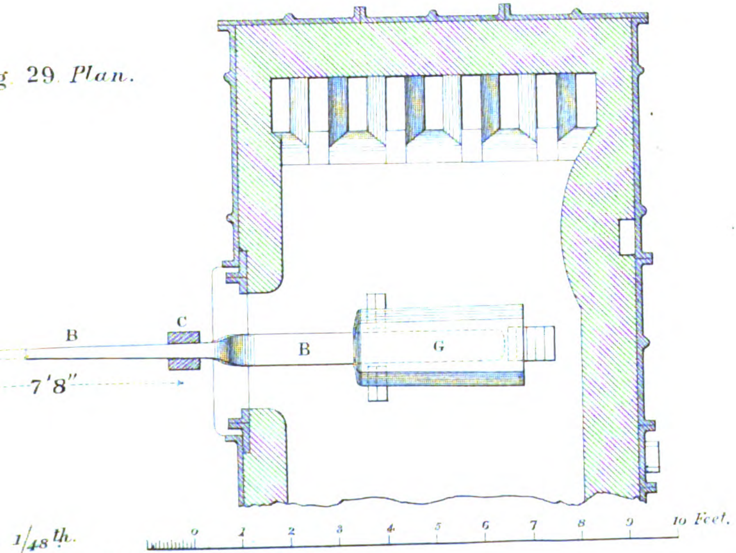
Plate 75.

Peel Bar for lifting and carrying the ingots.

28. *Elevation.*

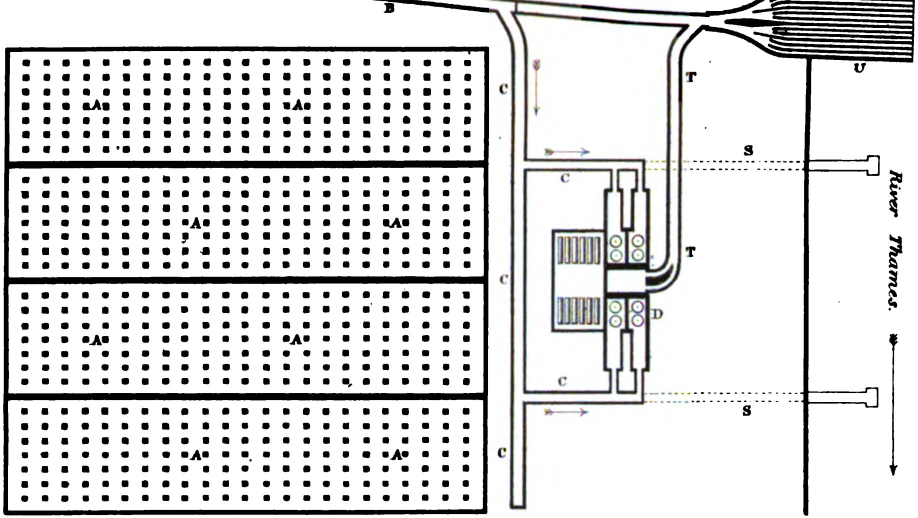


g 29. *Plan.*



1/48 th.

ngs Inst. M.E. 1867 Page 218.)



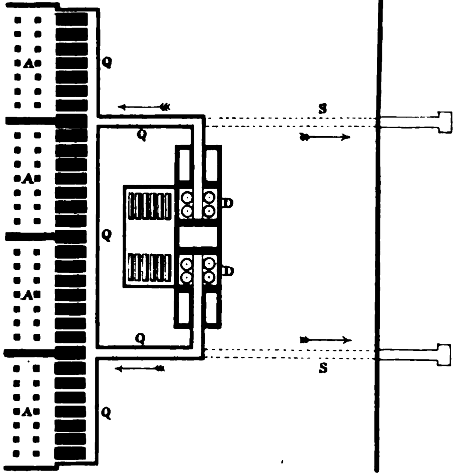
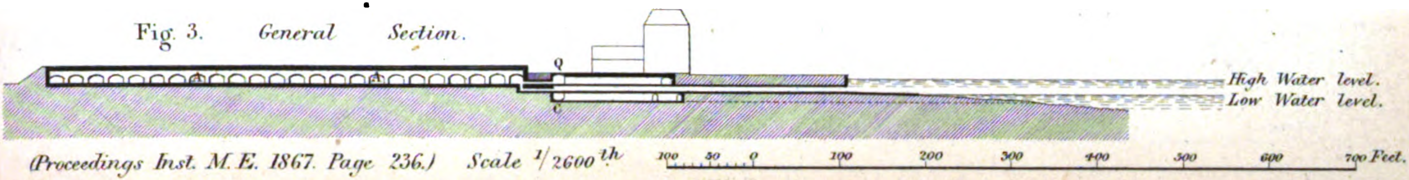


Fig. 3. *General Section.*



(Proceedings Inst. M. E. 1867. Page 236.) *Scale 1/2600th*

Fig. 4. Section through Culverts and Pumps.

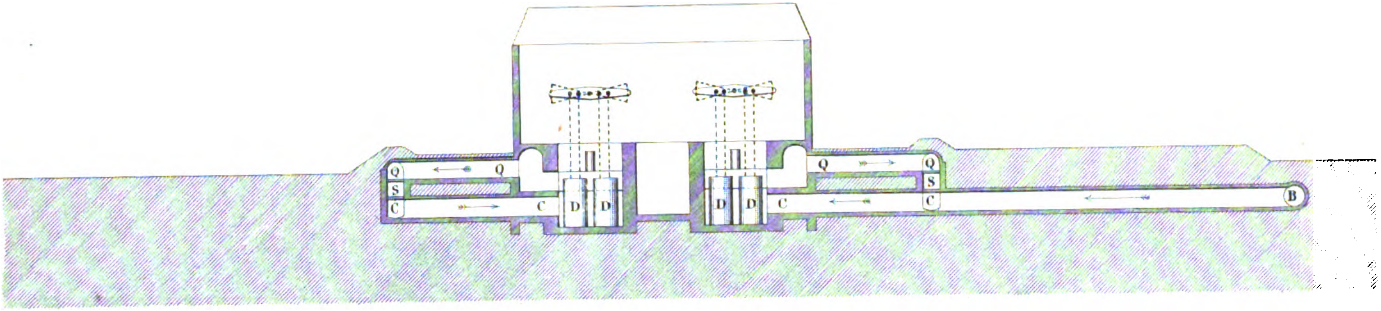
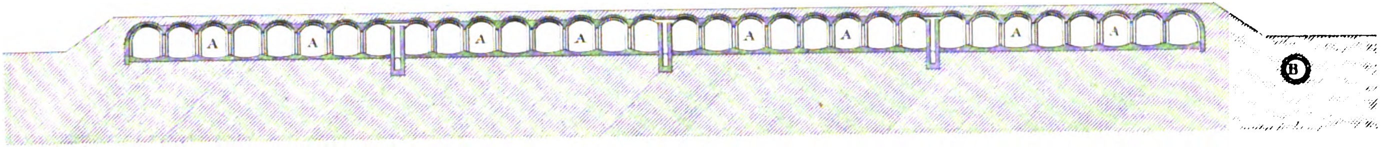
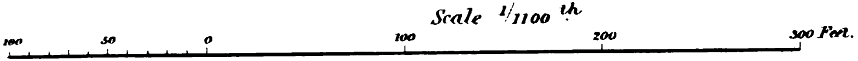


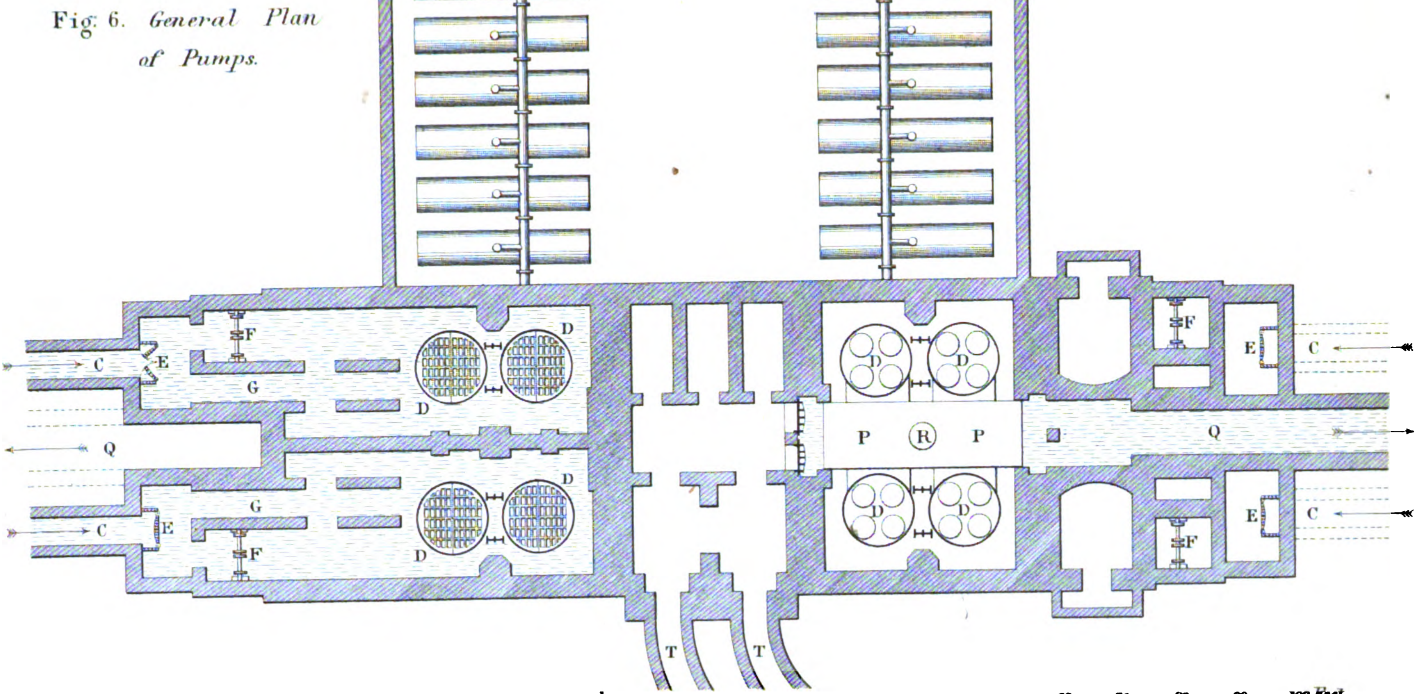
Fig. 5. Section through Reservoir.





(Proceedings Inst. M. E. 1867. Page 236.)

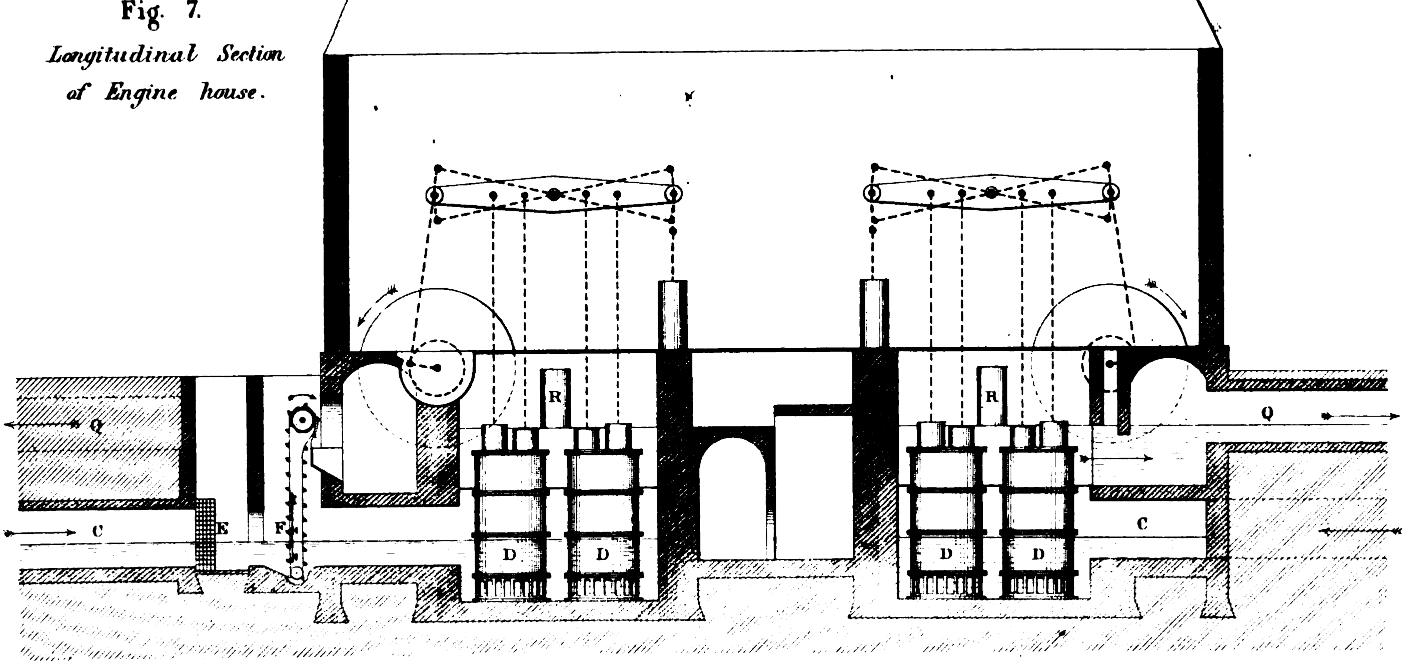
Fig: 6. *General Plan of Pumps.*



(Proceedings Inst. M.E. 1867. Page 236.) Scale 1/400 th

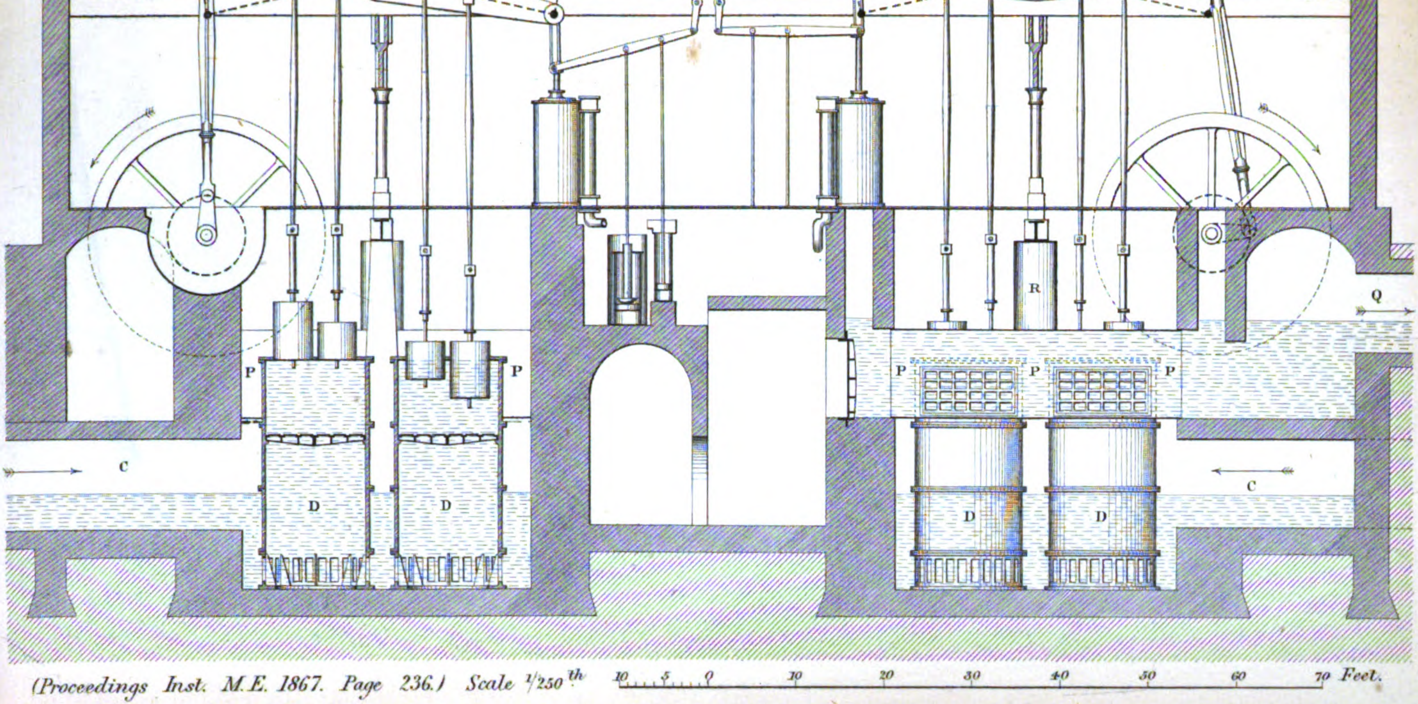
Fig. 7.

Longitudinal Section of Engine house.

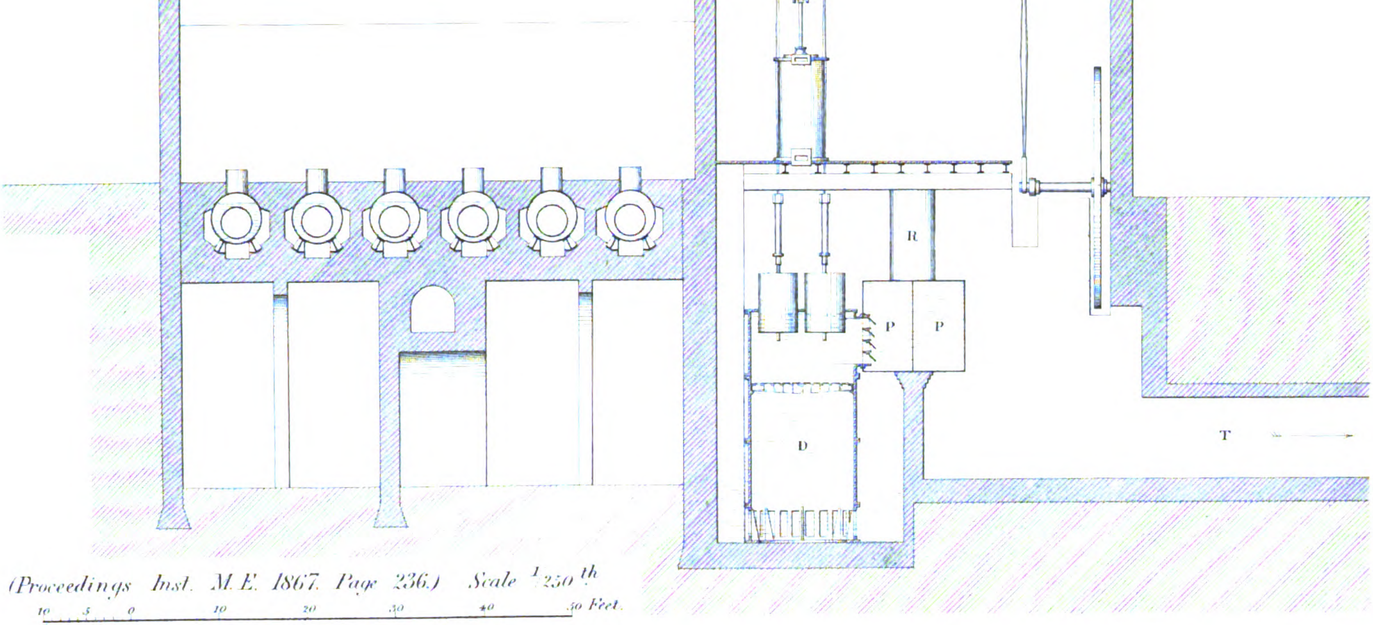


(Proceedings Inst. M.E. 1867. Page 236.)

Scale 1/400th.



(Proceedings Inst. M.E. 1867. Page 236.) Scale 1/250th



(Proceedings Inst. M.E. 1867. Page 236.) Scale $\frac{1}{250}$th.

CROSSNESS PUMPING ENGINES. *Plate 82.*

Fig. 10. *Vertical Section of Pump and Delivery Trough.*

Scale $1/70$th.

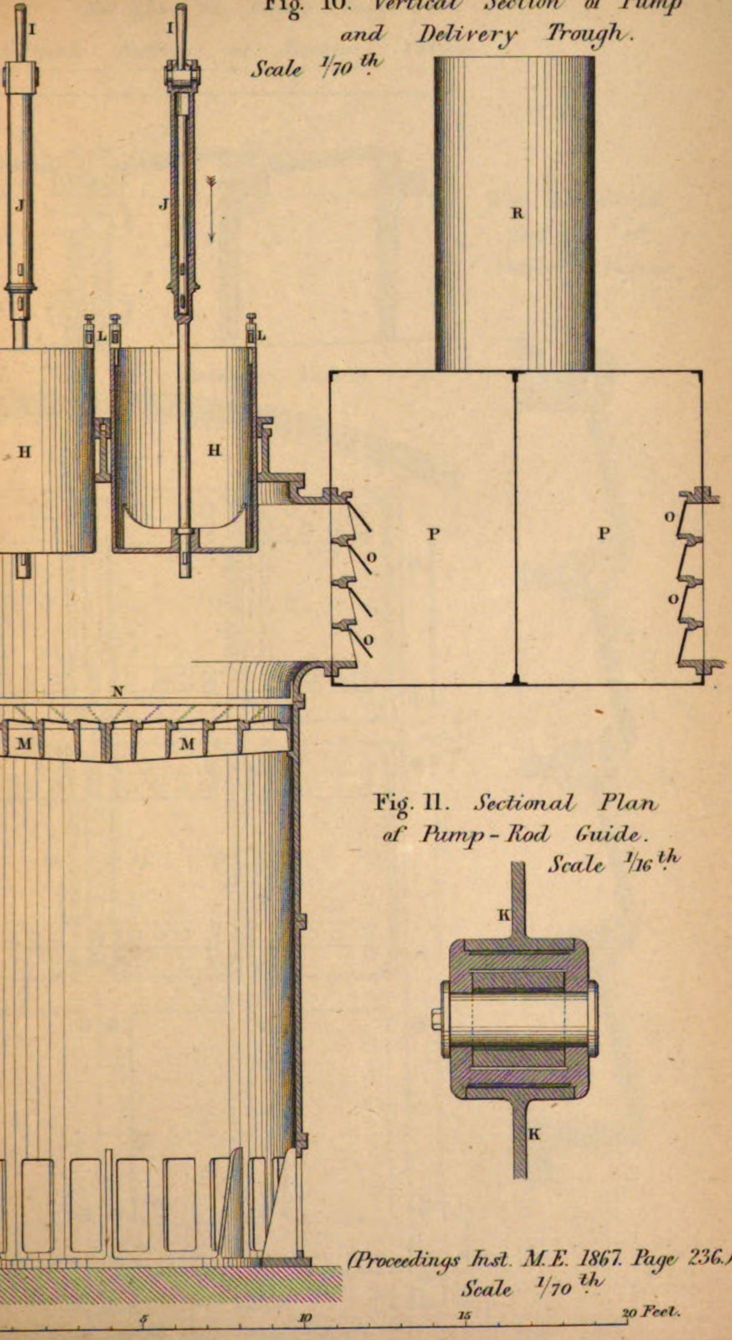


Fig. 11. *Sectional Plan of Pump-Rod Guide.*

Scale $1/16$th.

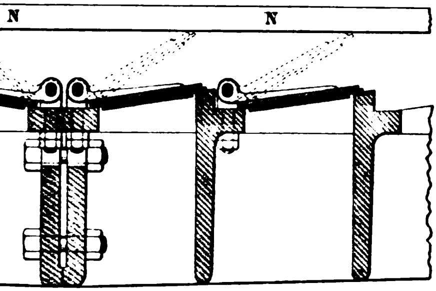
(Proceedings Inst. M.E. 1867. Page 236.)

Scale $1/70$th.

CROSSNESS PUMPING ENGINES. *Plate 83.*

Details of Pump Valves.

rtical Section of Suction Valves.



Plan of Suction Valves.

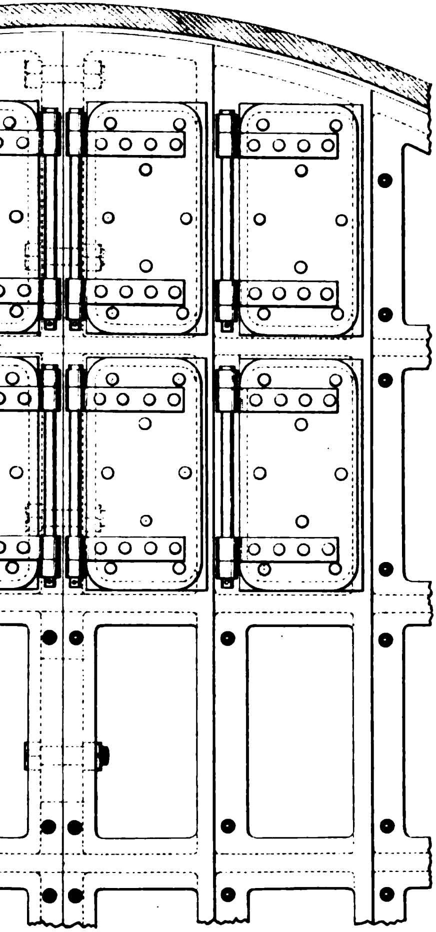
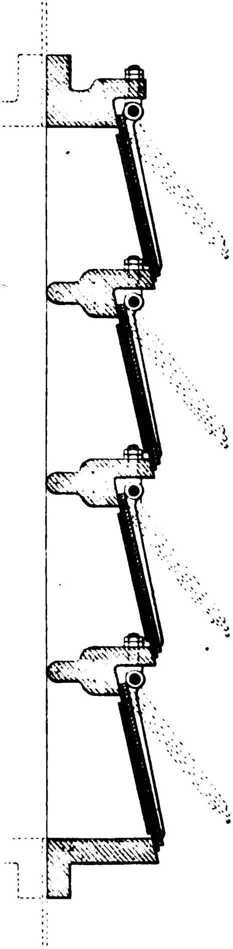


Fig. 14. *Vertical Section of Delivery Valves.*



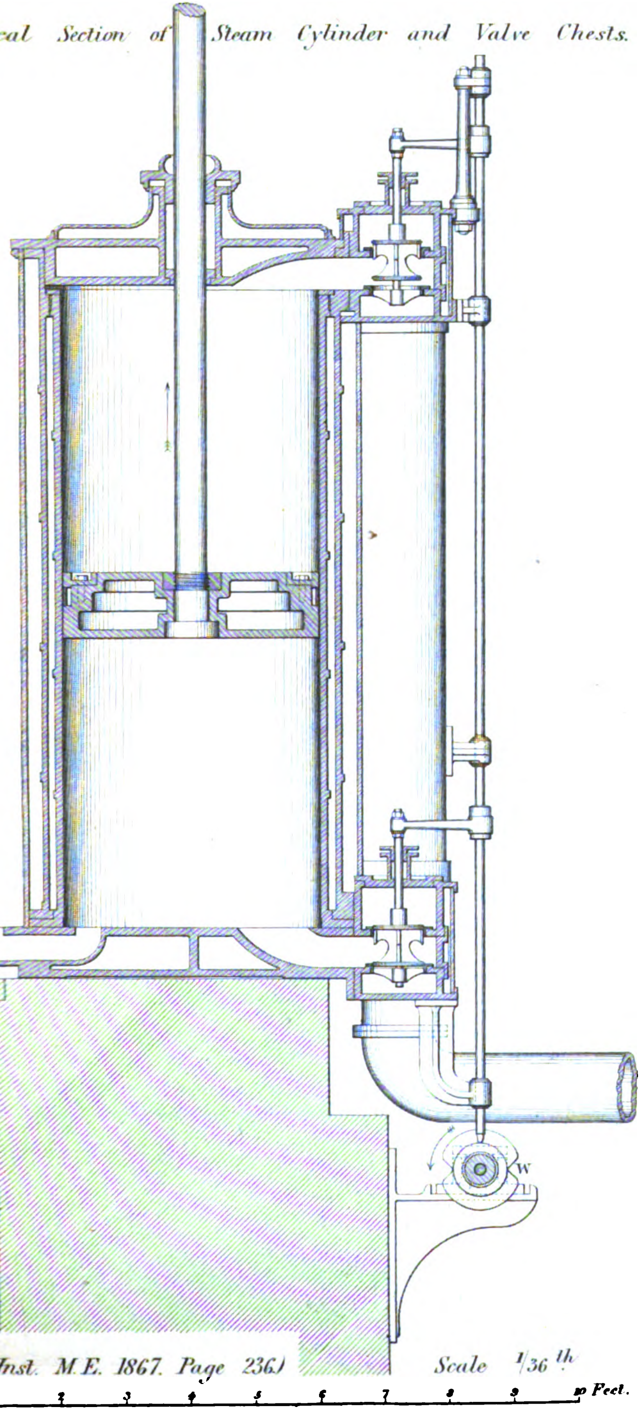
Inst. M.E. 1867. Page 236.)

Scale 1/16 th

0 10 20 30 40 50 *Inches.*

CROSSNESS PUMPING ENGINES. *Plate 84.*

cal Section of Steam Cylinder and Valve Chests.



Inst. M.E. 1867. Page 236)

Scale 1/36th

ROSSNESS PUMPING ENGINES. *Plate 85.*

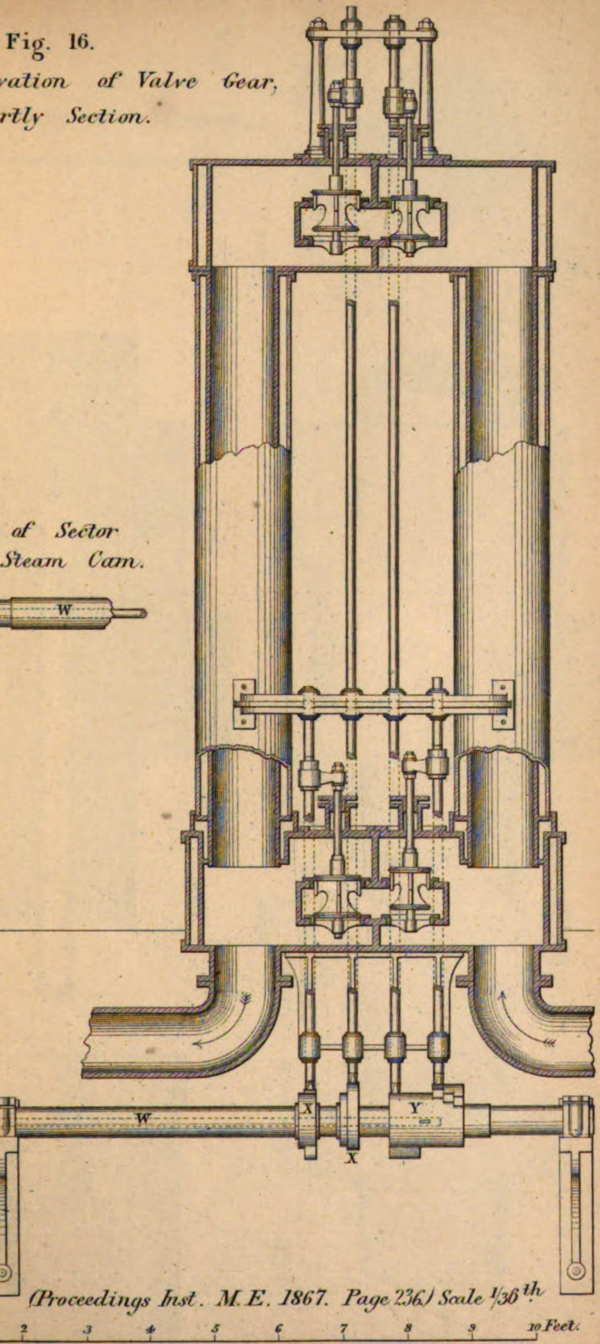
Fig. 16.

vation of Valve Gear,

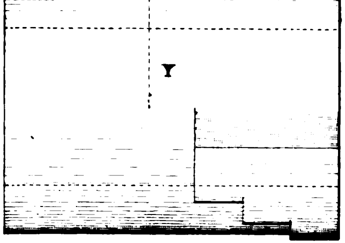
rtly Section.

of Sector

Steam Cam.



(Proceedings Inst. M.E. 1867. Page 236.) Scale 1/36th.



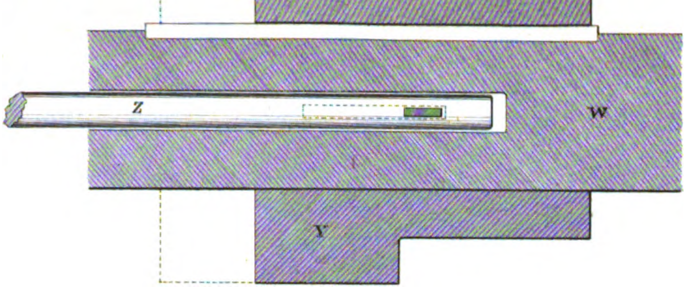


Fig. 20.

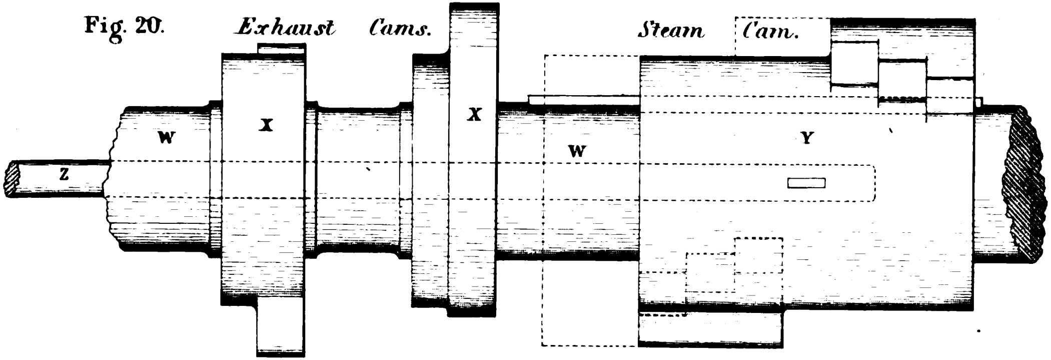
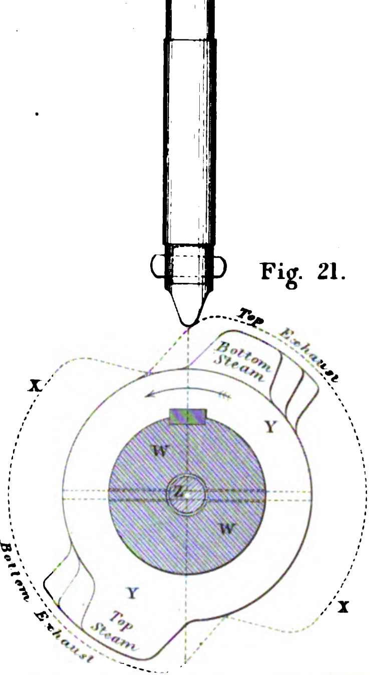
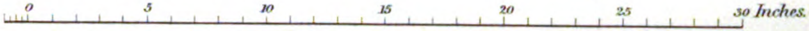


Fig. 21.

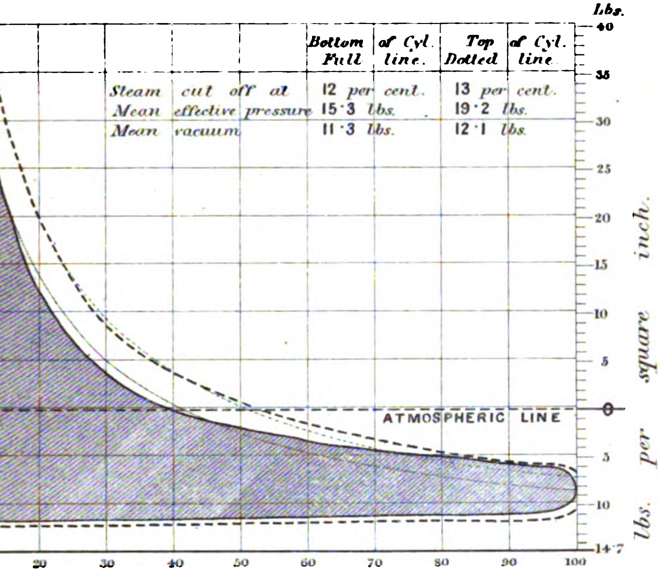


(Proceedings Inst. M. E. 1867. Page 236.) Scale 1/8 th



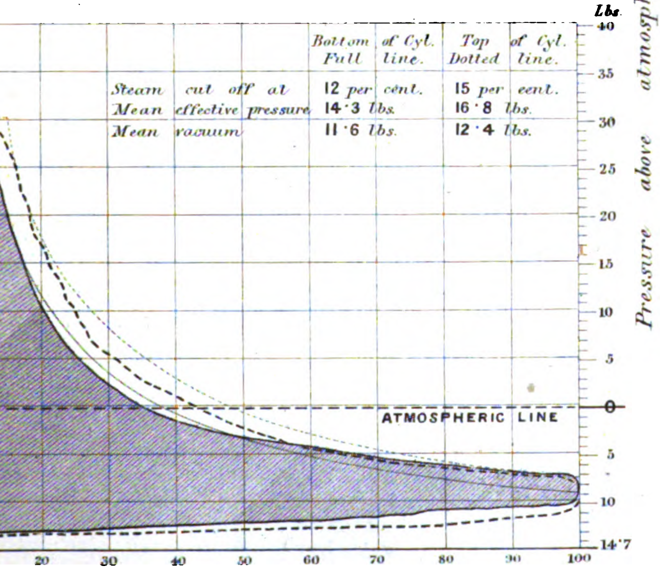
CROSSNESS PUMPING ENGINES. *Plate 87.*

Indicator Diagrams from "Alexandra" Engine.



	Bottom Full of Cyl. line.	*Top Dotted of Cyl. line.*
Steam cut off at	12 *per cent.*	13 *per cent.*
Mean effective pressure	15·3 *lbs.*	19·2 *lbs.*
Mean vacuum	11·3 *lbs.*	12·1 *lbs.*

ndicator Diagrams from "Albert Edward" Engine.



	Bottom Full of Cyl. line.	*Top Dotted of Cyl. line.*
Steam cut off at	12 *per cent.*	15 *per cent.*
Mean effective pressure	14·3 *lbs.*	16·8 *lbs.*
Mean vacuum	11·6 *lbs.*	12·4 *lbs.*

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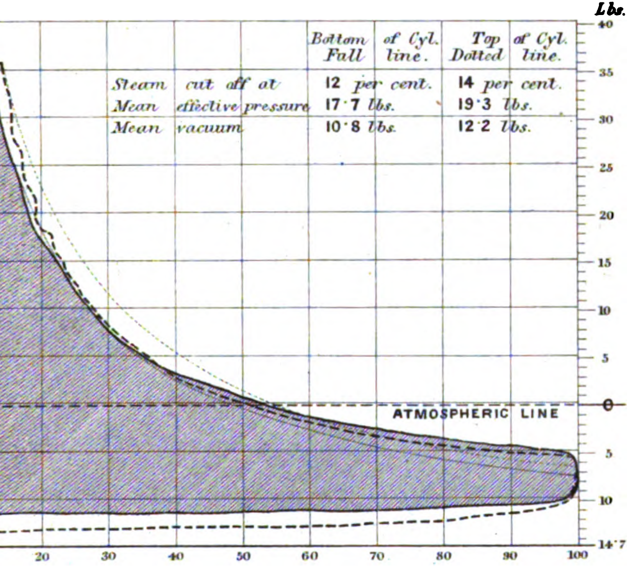
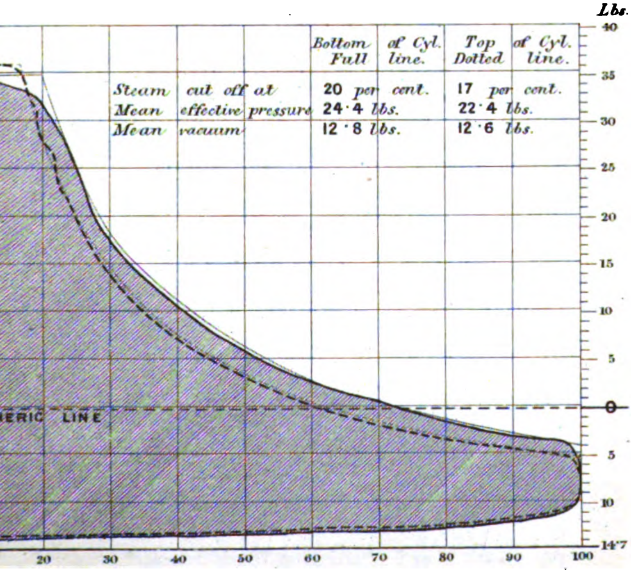
CROSSNESS PUMPING ENGINES. *Plate 88.*

Indicator Diagrams from "Prince Consort" Engine.



	Bottom Fall of Cyl. line.	Top Dotted of Cyl. line.
Steam cut off at	12 per cent.	14 per cent.
Mean effective pressure	17·7 lbs.	19·3 lbs.
Mean vacuum	10·8 lbs.	12·2 lbs.

Indicator Diagrams from "Victoria" Engine.



	Bottom Full of Cyl. line.	Top Dotted of Cyl. line.
Steam cut off at	20 per cent.	17 per cent.
Mean effective pressure	24·4 lbs.	22·4 lbs.
Mean vacuum	12·8 lbs.	12·6 lbs.

Pressure above atmosphere, lbs. per square inch.

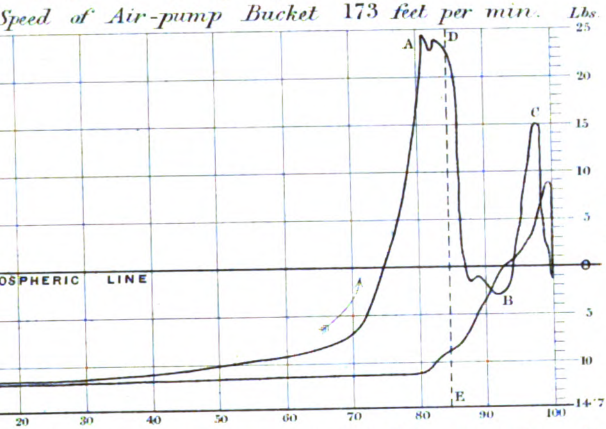
Plate 89.

Air - Pump Diagrams

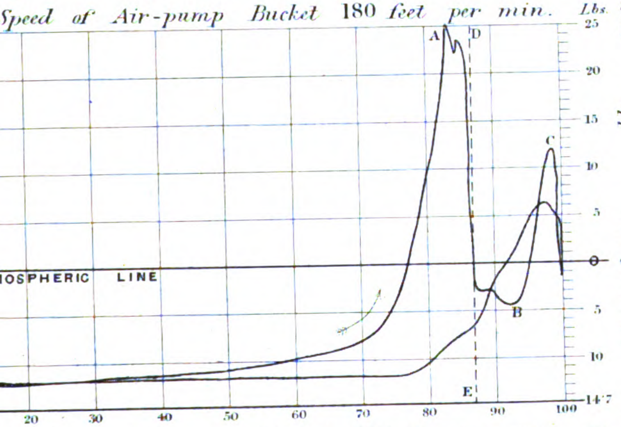
om engines of Steamship "Newton."

Stroke of Air-pump 20 inches.

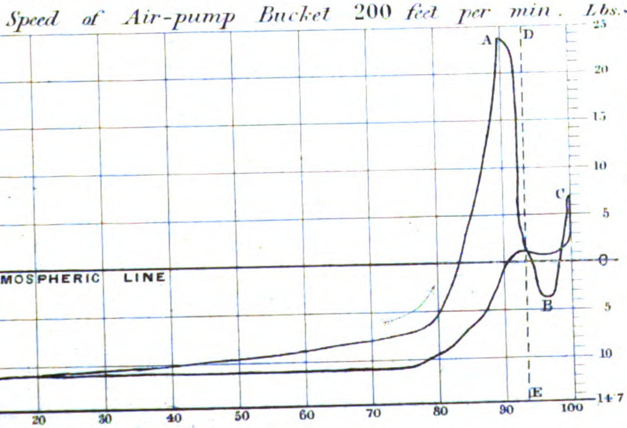
Speed of Air-pump Bucket 173 feet per min.



Speed of Air-pump Bucket 180 feet per min.



Speed of Air-pump Bucket 200 feet per min.



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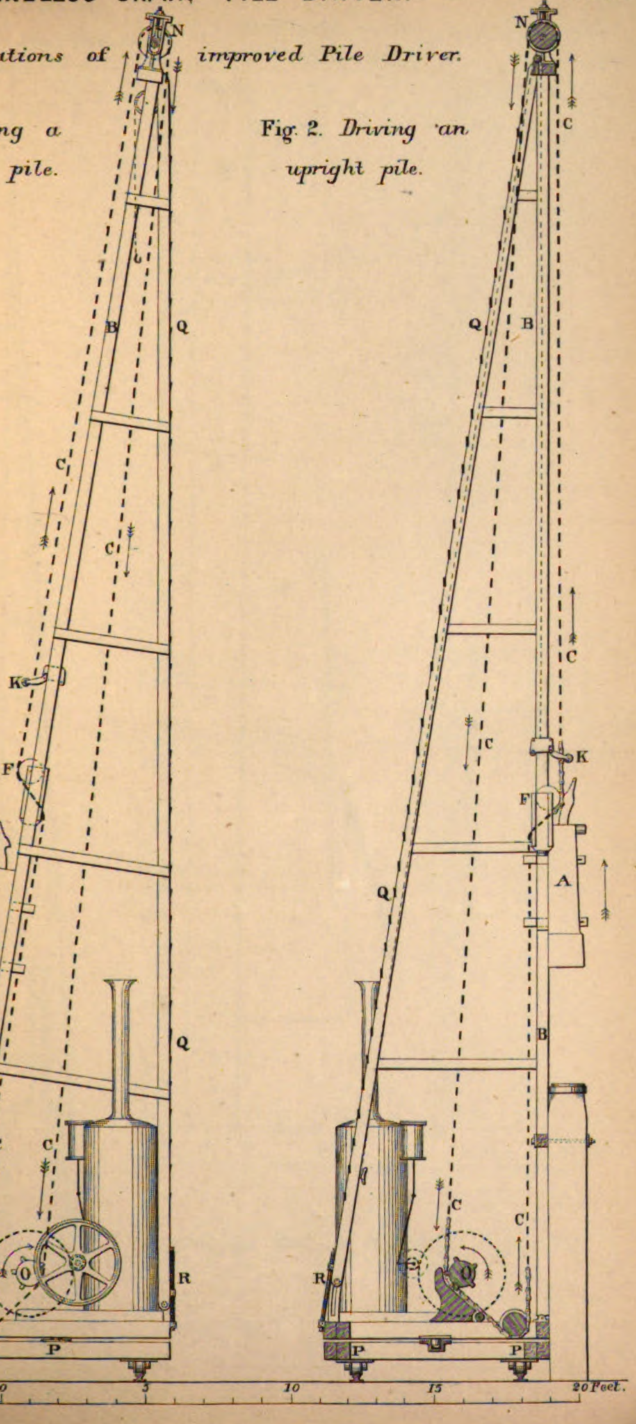
NDLESS-CHAIN PILE DRIVER.

Plate 90.

tions of improved Pile Driver.

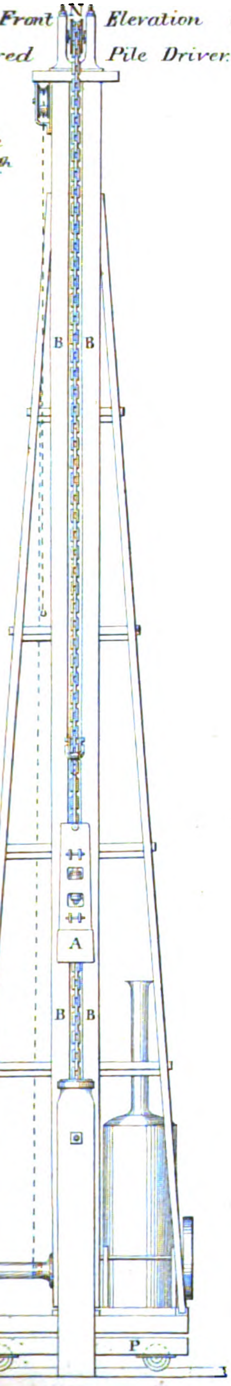
ng a
pile.

Fig. 2. *Driving an upright pile.*

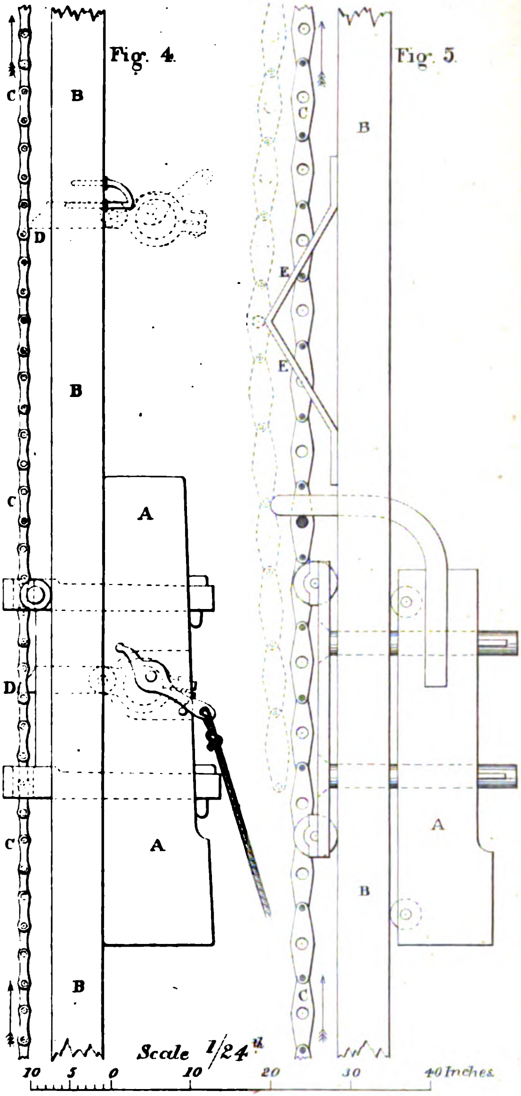


ENDLESS-CHAIN PILE DRIVER.

Front Elevation of
ed Pile Driver.



Ordinary modes of attachment
of Chain to Ram. Scale 1/24th



(Proceedings Inst. M.E. 1867 Page 255)

Scale 1/80th

0 5 10 15 Feet.

ENDLESS-CHAIN PILE DRIVER.

Plate 92.

ig. 6. *Ram*
ing raised.

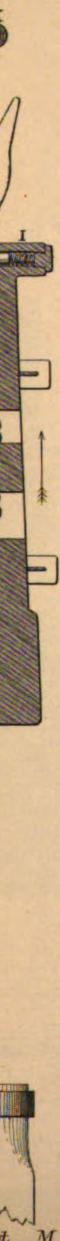


Fig. 7. *Moment of release.*

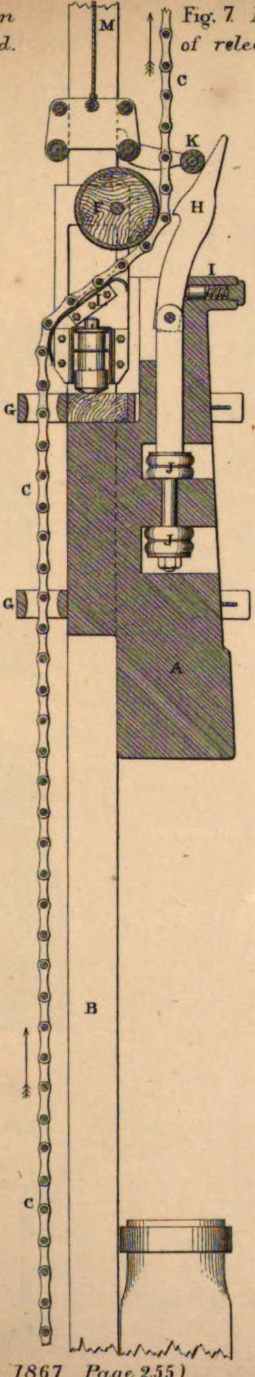
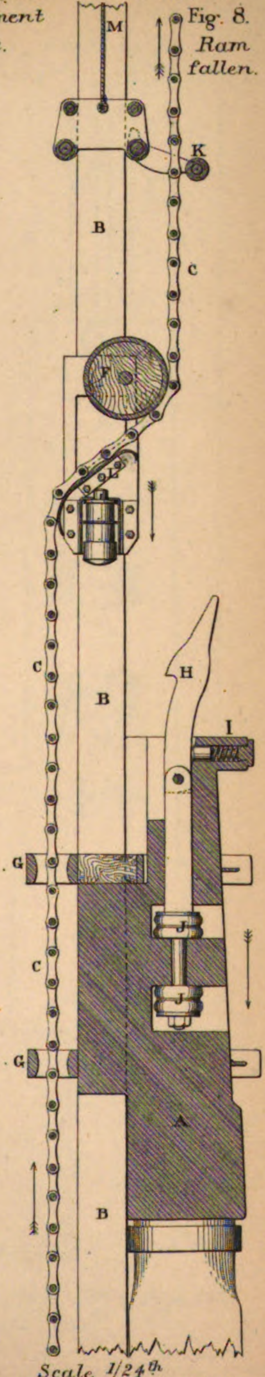


Fig. 8. *Ram fallen.*



t. M.E. 1867. Page 255)

Scale 1/24th

10 20 30 40 50 60 70 80 *Inches.*

ENDLESS-CHAIN PILE DRIVER.

Plate 93.

Fig 9. *Vertical Section of Ram.*

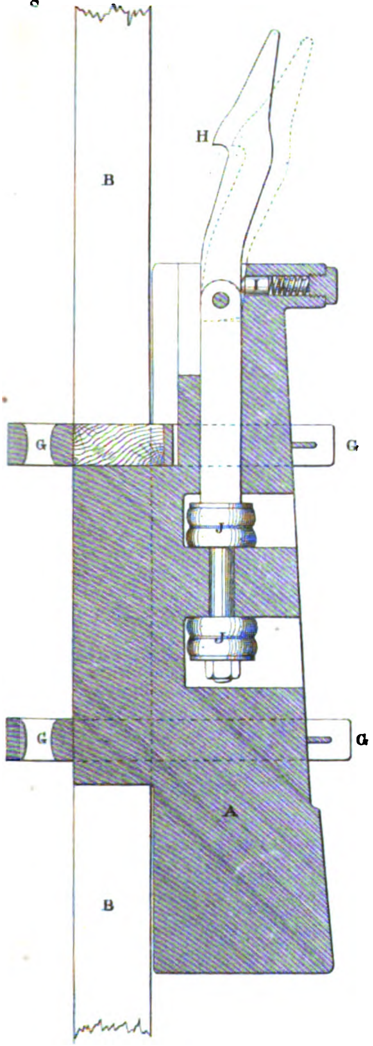


Fig. 10. *Front Elevation.*

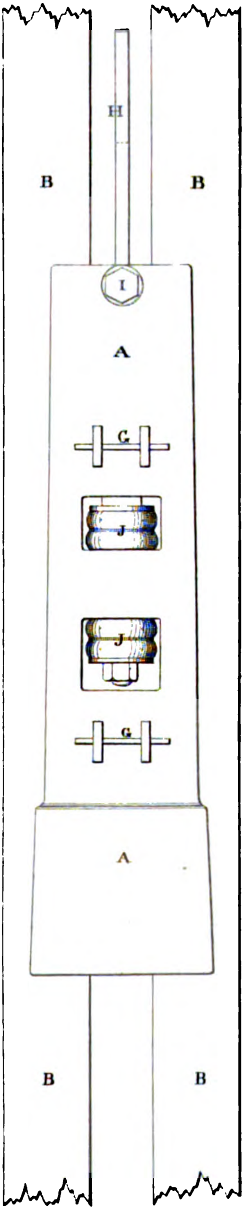
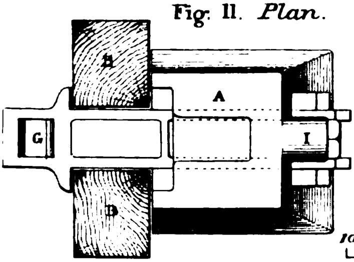


Fig. 11. *Plan.*



(Proceedings Inst. M.E. 1867. Page 255)

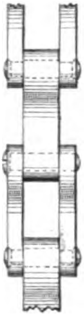
Scale 1/16th

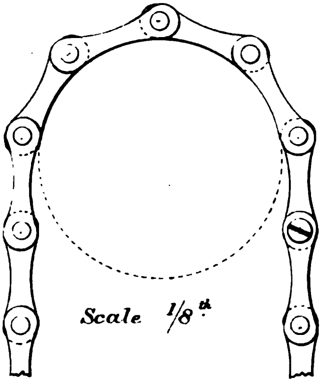
10 5 0 10 20 *Inches.*

ENDLESS-CHAIN PILE DRIVER. *Plate 94.*

Fig. 12. *Lifting Chain.*

Fig. 13.





Scale 1/8th.

Fig. 14.

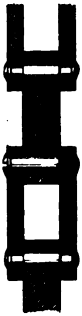


Fig. 15. *Side Elevation of Striker Off.*

Scale 1/16th.

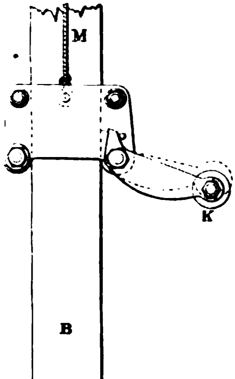


Fig. 17. *Plan.*

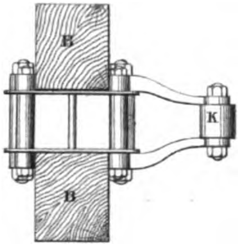


Fig. 16. *Front Elevation.*

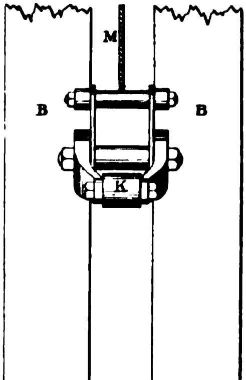


Fig. 18. *Side Elevation of Follower.*

Scale 1/16th.

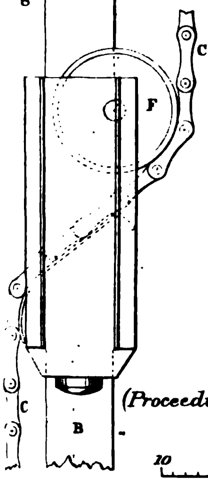


Fig. 20. *Plan.*

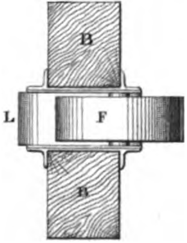
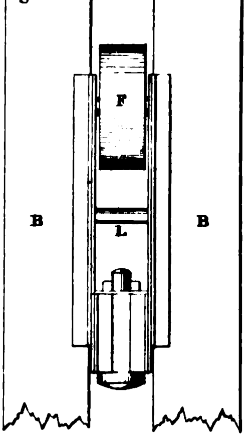


Fig. 19. *Front Elevation.*



(Proceedings Inst. M.E. 1867. Page 255)

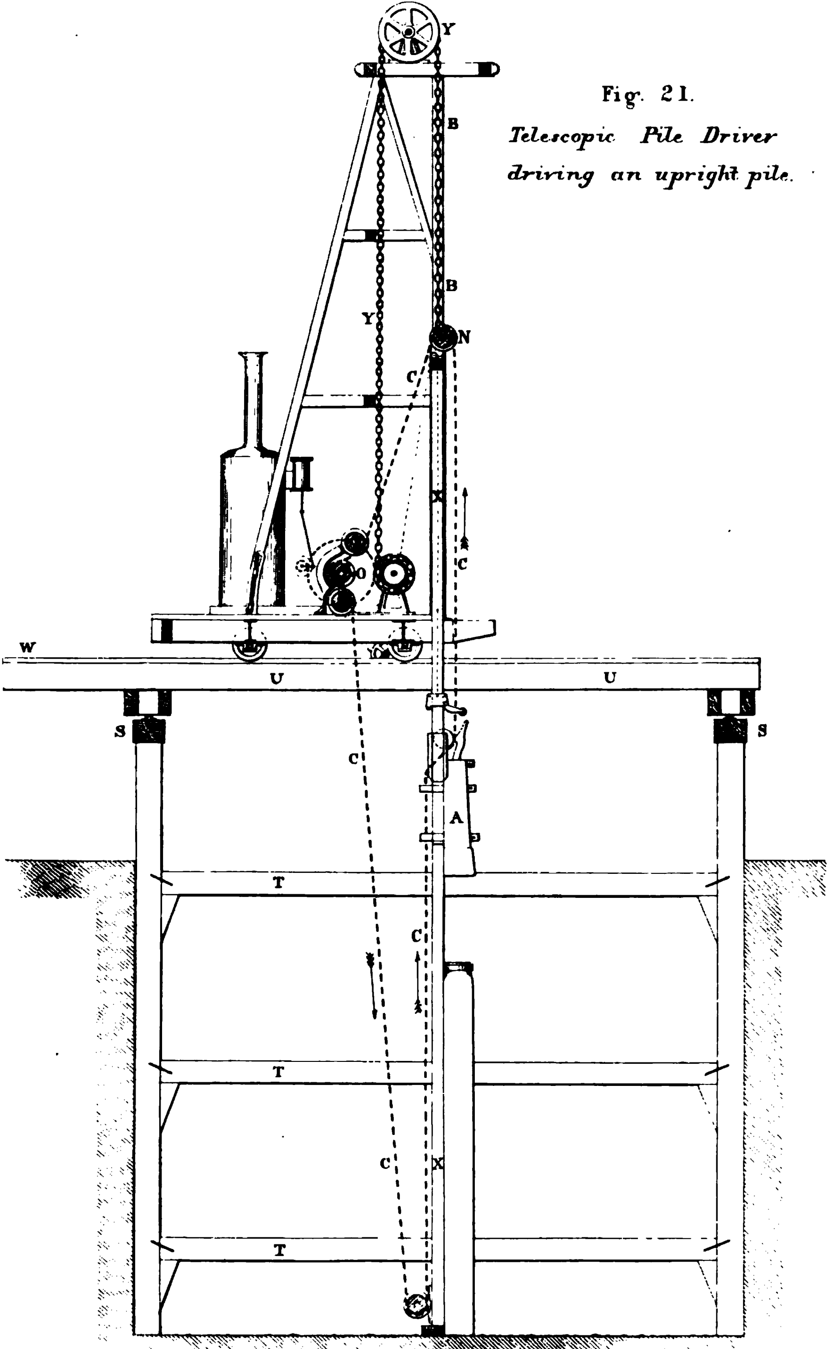
Scale 1/16th.

ENDLESS-CHAIN PILE DRIVER.

Plate 95.

Fig. 21.

Telescopic Pile Driver driving an upright pile.



(Proceedings Inst. M. E. 1867 Page 255)

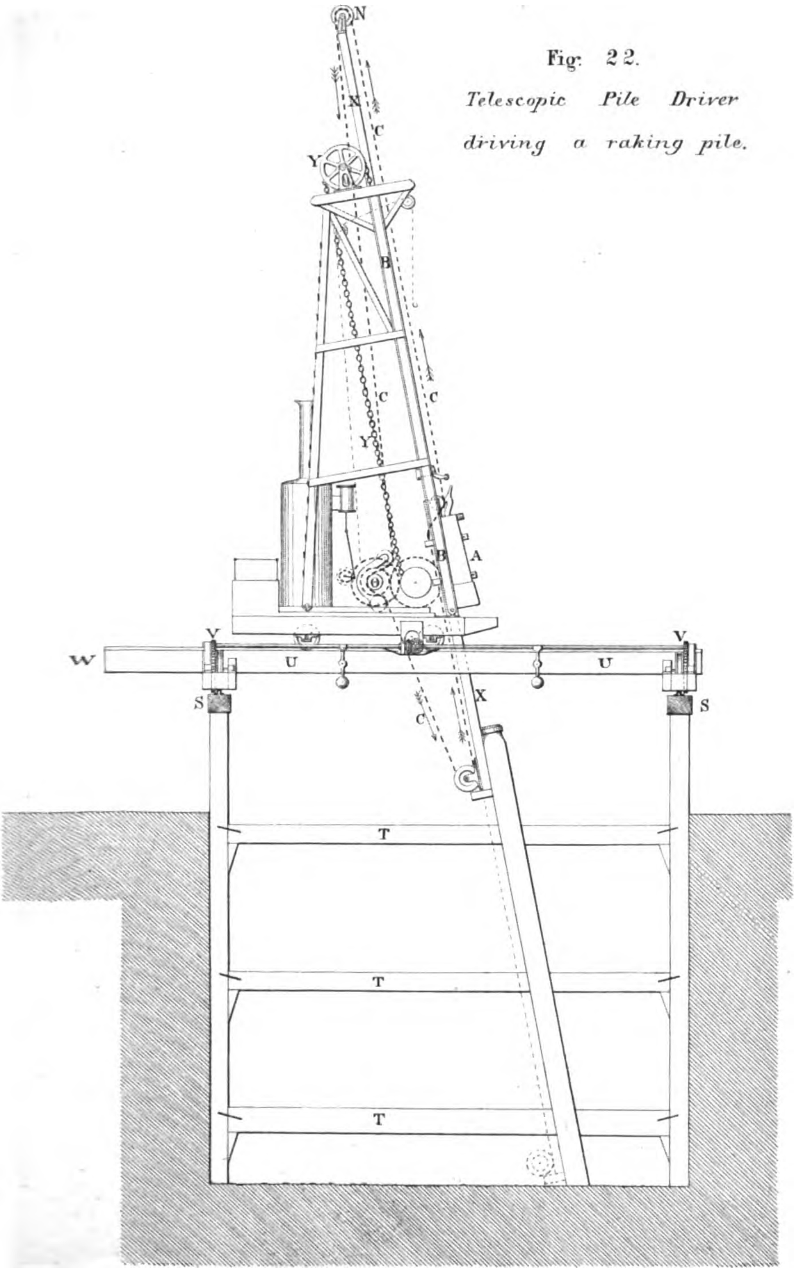
Scale 1/100th

0 5 10 15 20 25 30 Feet.

ENDLESS - CHAIN PILE DRIVER. *Plate 96.*

Fig: 22.

Telescopic Pile Driver driving a raking pile.



Scale 1/120th. 10 5 0 10 20 *Feet.*

(Proceedings Inst. M.E. 1867. Page 255)

ENDLESS-CHAIN PILE DRIVER.

Plate 97.

Fig. 23. *Cast-iron Shoe for square piles.*

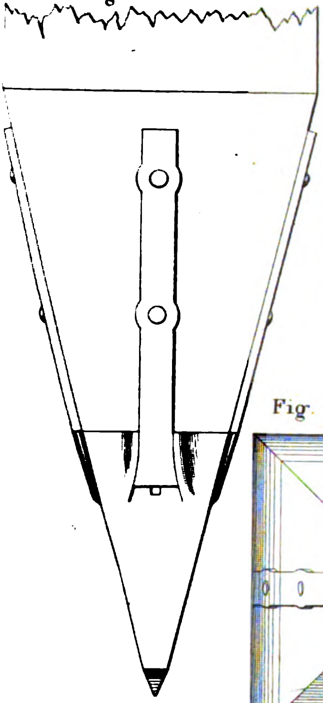


Fig. 24.

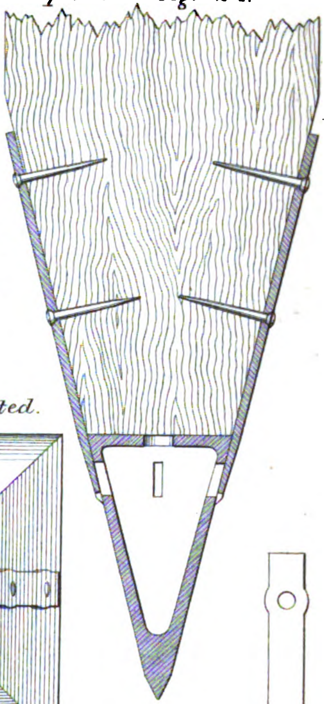


Fig. 25. *Plan of Shoe.*

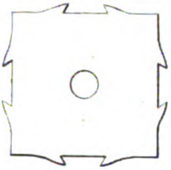


Fig. 26. *Plan inverted.*

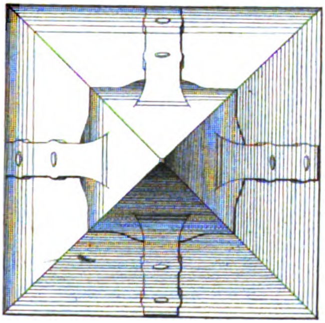


Fig. 27. *Strap.*

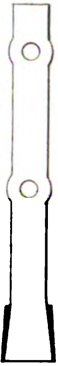


Fig. 28. *Cast-iron Shoe for sheet piles.*

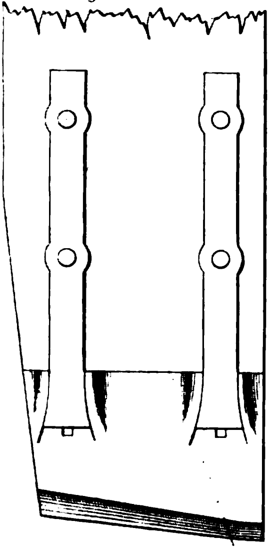


Fig. 29.

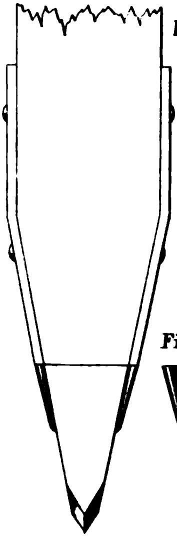


Fig. 30. *Plan of Shoe.*

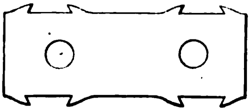


Fig. 31. *Sections of Shoe.*

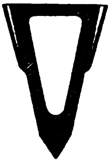
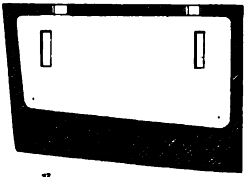


Fig. 32.



(*Proceedings Inst. M.E. 1867. Page 255*)

Scale 1/8th

STEAM STEERING ENGINE.

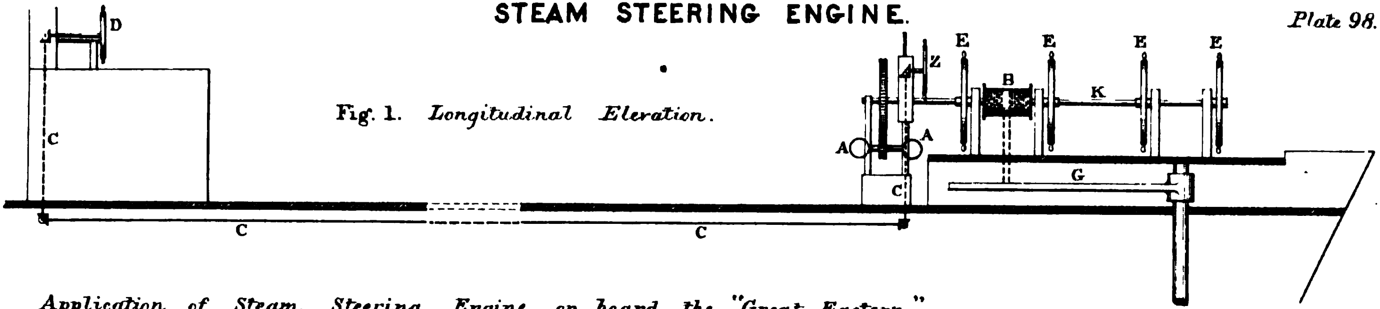


Fig. 1. *Longitudinal Elevation.*

Application of Steam Steering Engine on board the "Great Eastern."

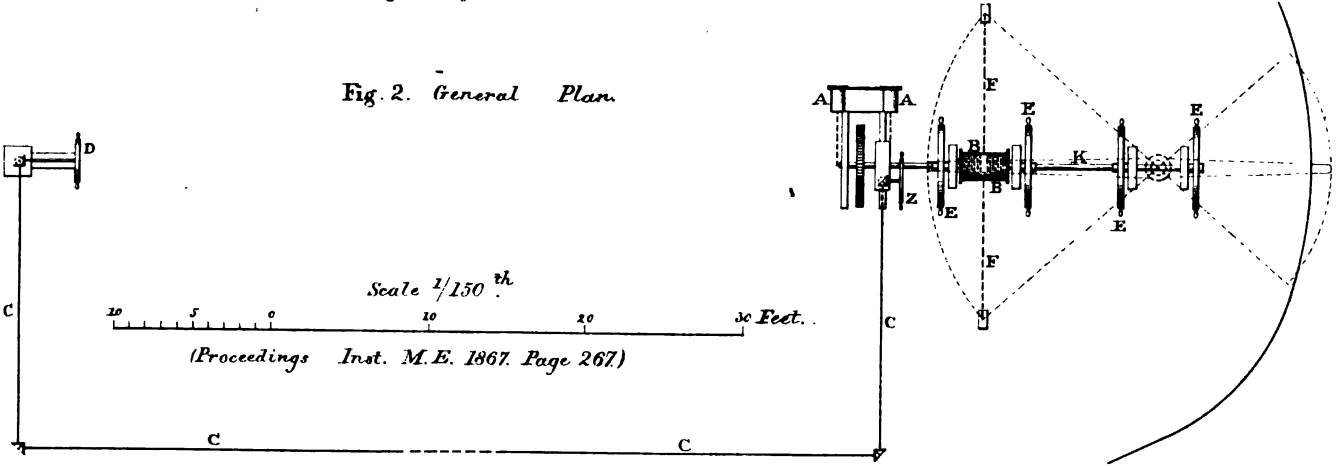


Fig. 2. *General Plan.*

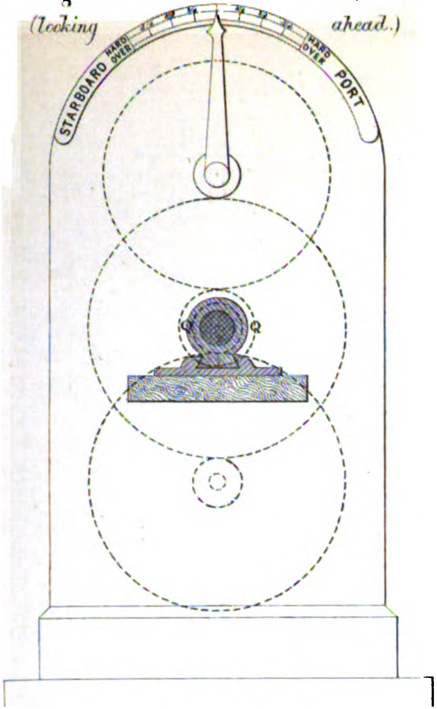
Scale 1/150th.

(Proceedings Inst. M.E. 1867. Page 267)

STEAM STEERING ENGINE.

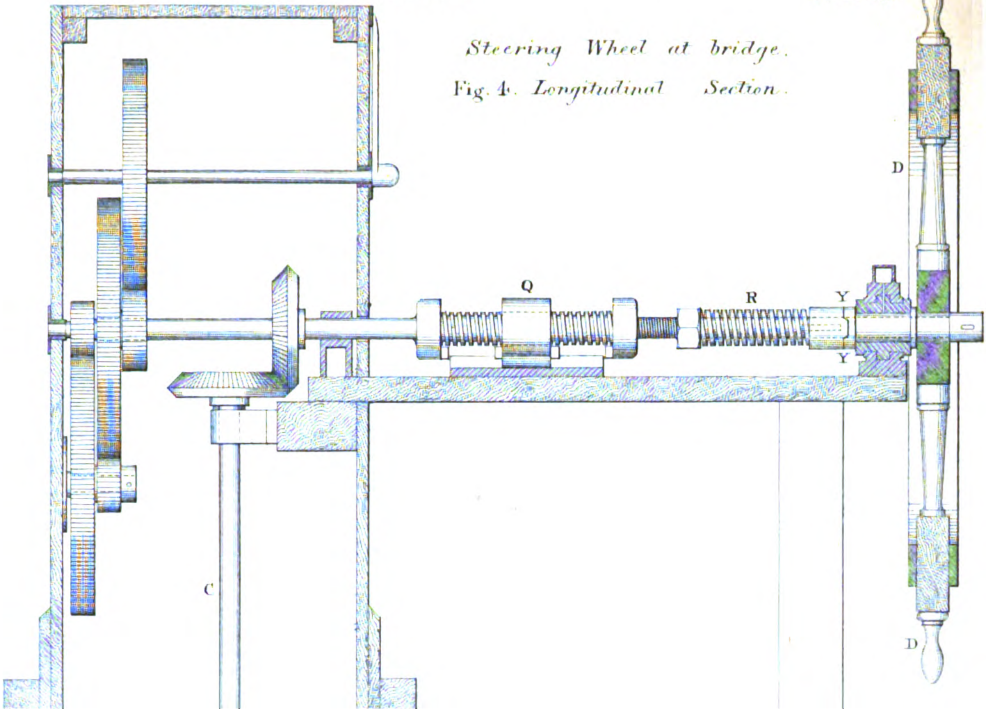
Plate 99.

Fig. 3. *Transverse Section,* *(looking ahead.)*



Steering Wheel at bridge.

Fig. 4. *Longitudinal Section.*

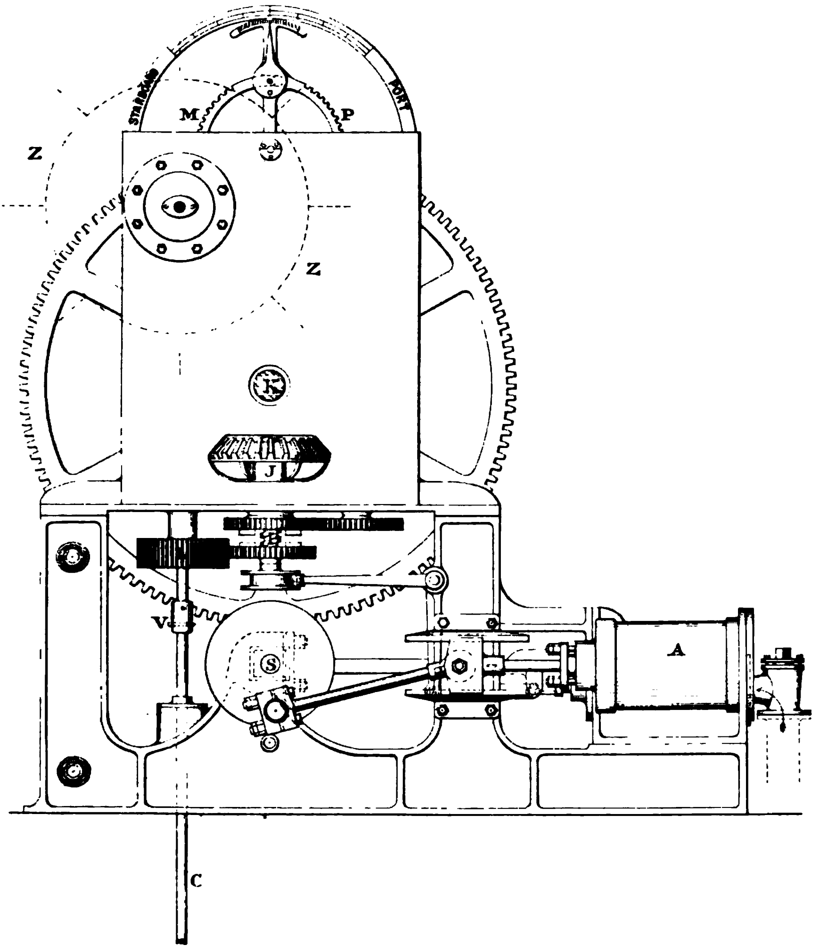


STEAM STEERING ENGINE.

Plate 100.

Fig. 3. *Elevation of Steam Steering Engine.*

(looking ahead.)



(Proceedings Inst. M.E. 1867. Page 267.) *Scale 1/24th.*

STEAM STEERING ENGINE.

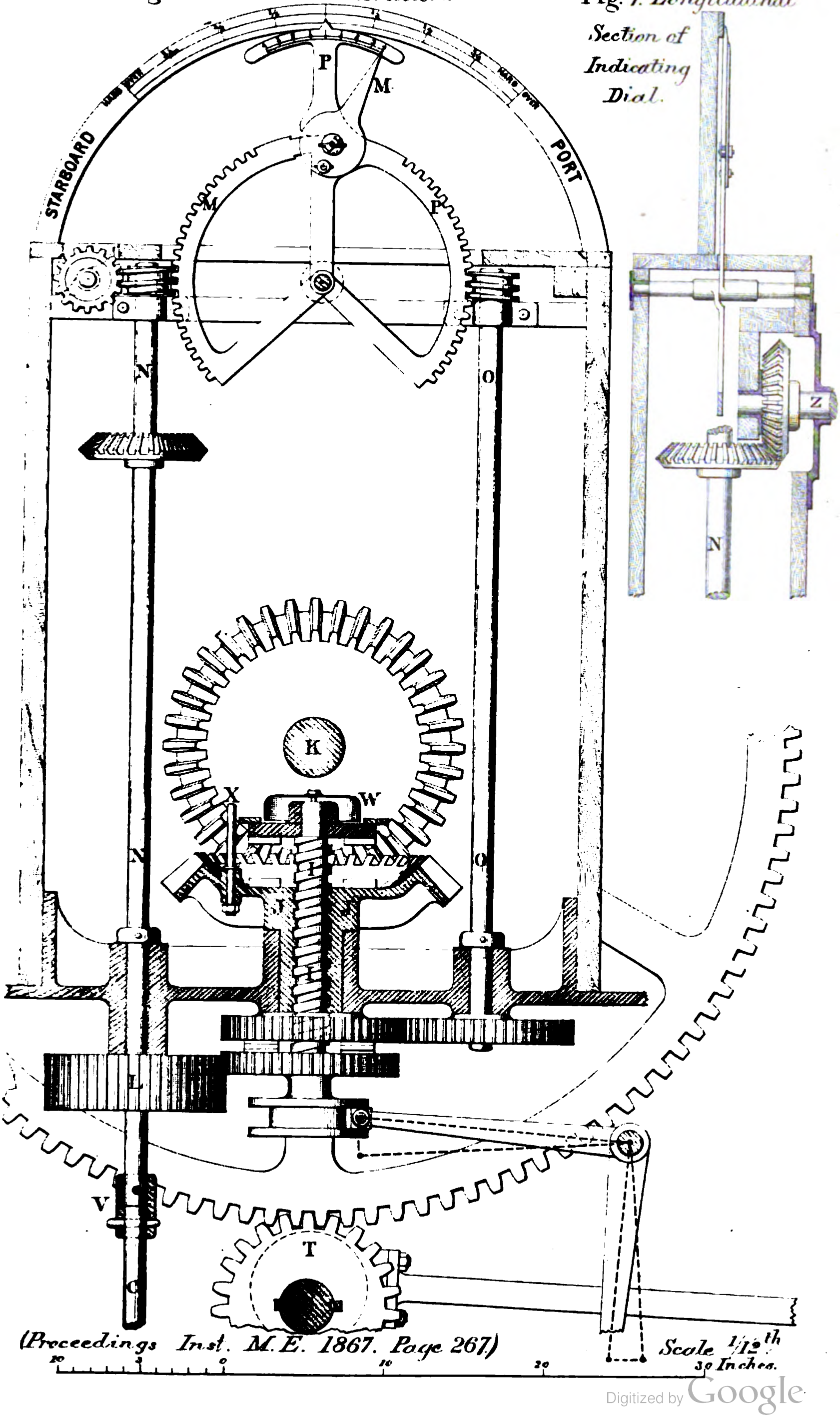


Fig. 6. Sectional Elevation.

Fig. 7. Longitudinal Section of Indicating Dial.

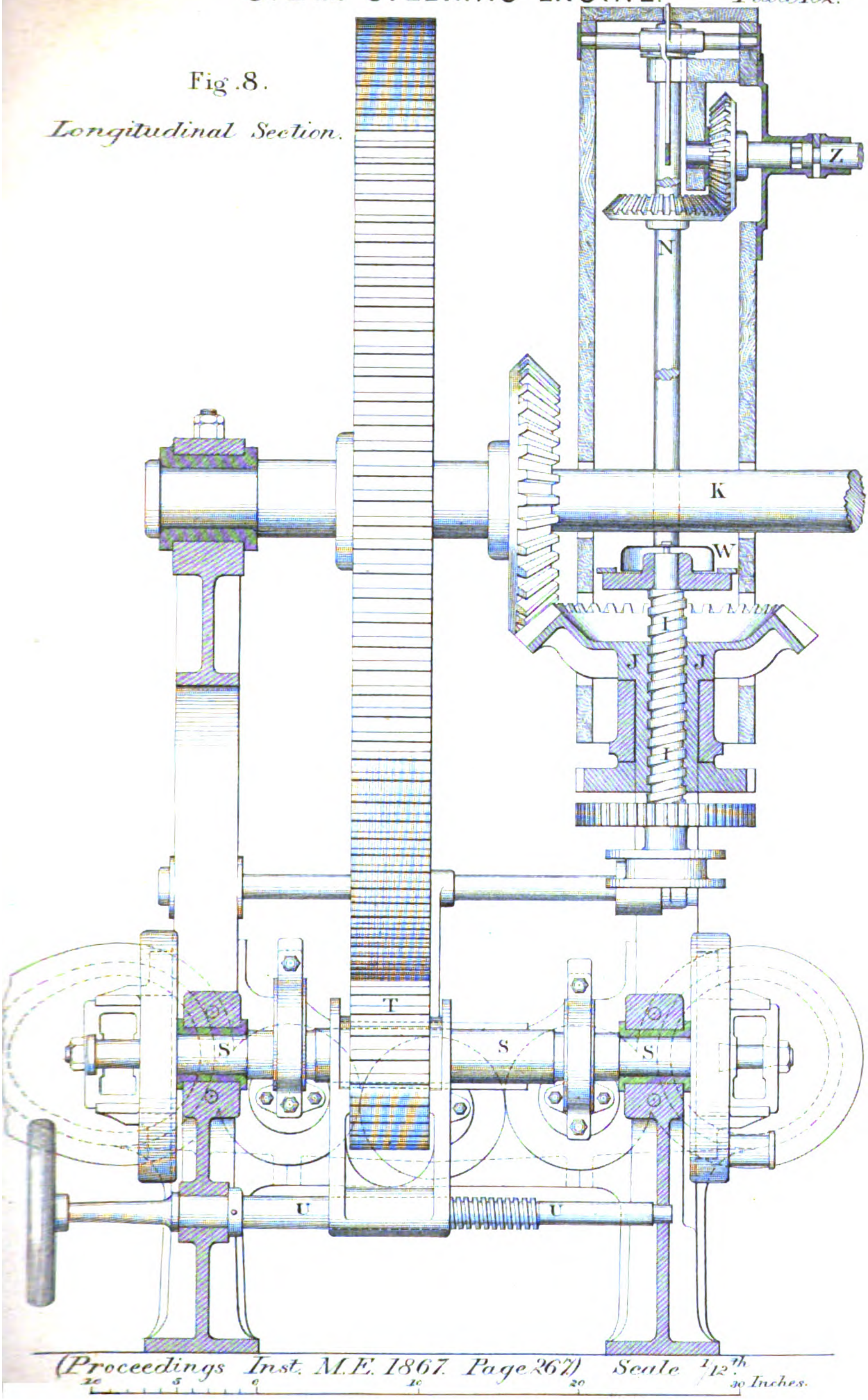
(Proceedings Inst. M.E. 1867. Page 267.)

Scale $1/12^{th}$

STEAM STEERING ENGINE.

Fig. 8.

Longitudinal Section.



(Proceedings Inst. M.E. 1867. Page 267.) Scale 1/12th.

STEAM STEERING ENGINE. *Plate 103.*

Fig. 9. *Plan of Signal Bell.*

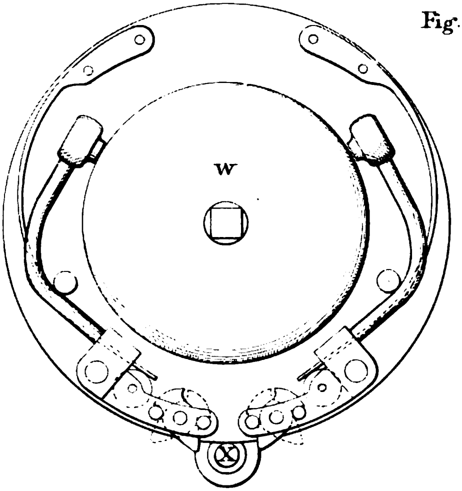
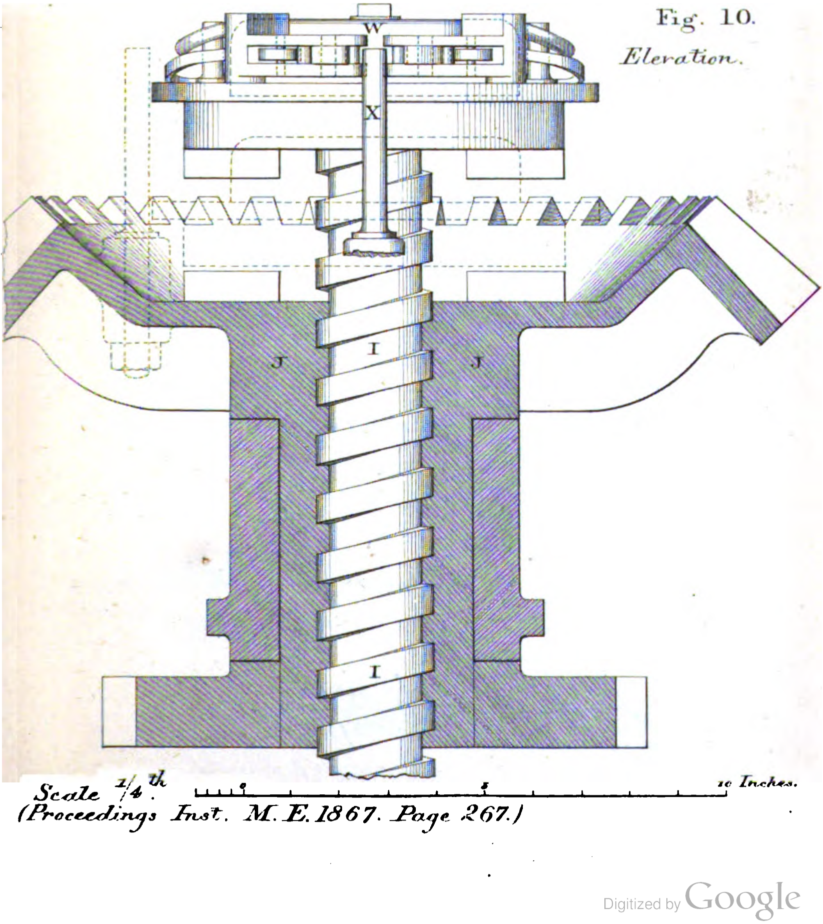


Fig. 10. *Elevation.*

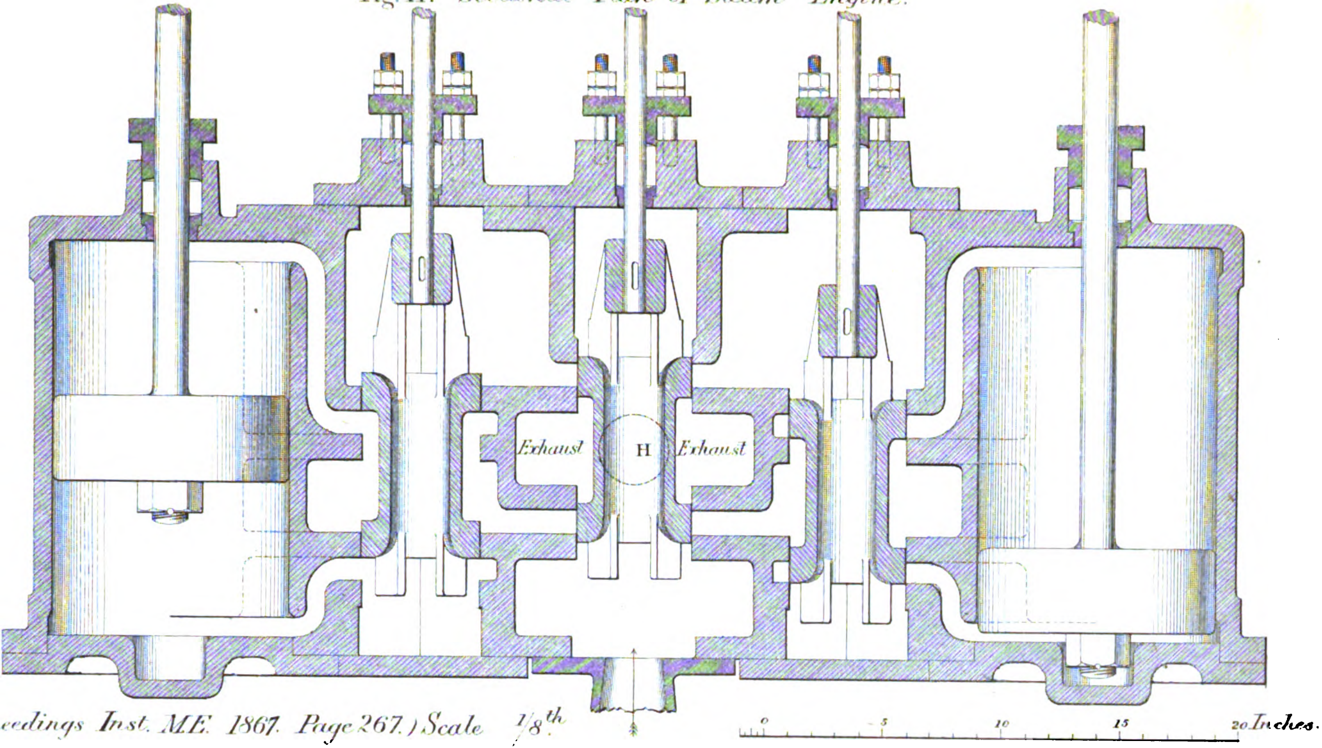


Scale $\frac{1}{4}$ th. 0 5 10 *Inches.*

(Proceedings Inst. M. E. 1867. Page 267.)

STEAM STEERING ENGINE.

Fig. 11. *Sectional Plan of Steam Engine.*



(Proceedings Inst. M.E. 1867. Page 267.) Scale 1/8th.

STEAM STEERING ENGINE.

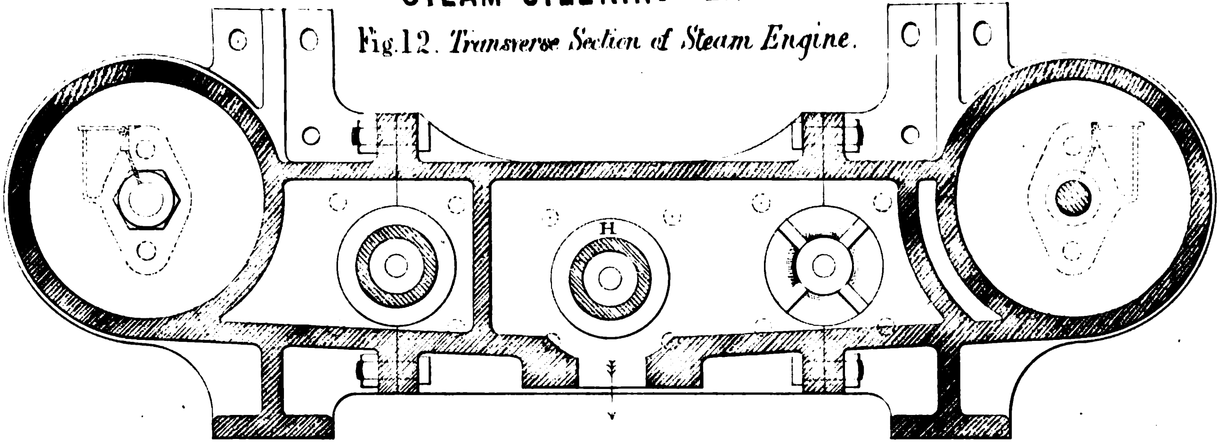
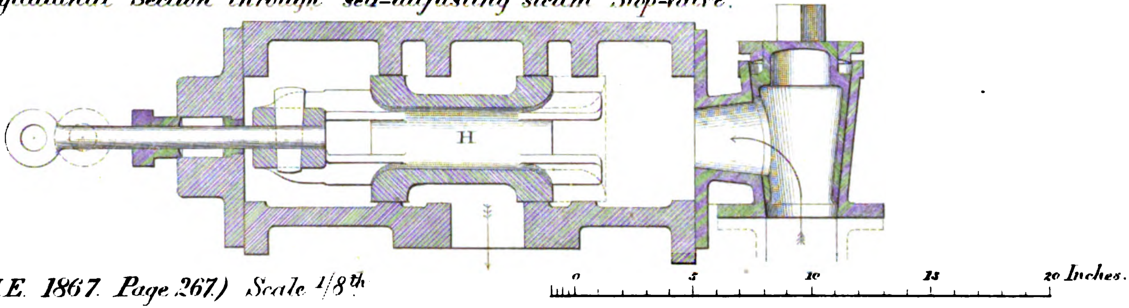


Fig. 12. *Transverse Section of Steam Engine.*

Fig. 13. *Longitudinal Section through self-adjusting steam Stop-Valve.*



(Proceedings Inst. M.E. 1867. Page 267.) *Scale 1/8th.*

INSTITUTION

OF

MECHANICAL ENGINEERS.

PROCEEDINGS.

1868.

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LIST OF MEMBERS,

WITH YEAR OF ELECTION.

1868.

MEMBERS.

1861. **Abel**, Charles Denton, 20 Southampton Buildings, London, W.C.
1866. **Adams**, William, Locomotive Superintendent, North London Railway, Bow, London, E.
1848. **Adams**, William Alexander, Newbold Beeches, Leamington.
1859. **Adamson**, Daniel, Newton Moor Iron Works, Hyde, near Manchester.
1861. **Addenbrooke**, George, Rough Hay Furnaces, Darlaston, near Wednesbury.
1851. **Addison**, John, 6 Delahay Street, Westminster, S.W.
1858. **Albaret**, Auguste, Engine Works, Liancourt, Oise, France.
1847. **Allan**, Alexander, Bridge Street, Worcester.
1865. **Allen**, William Daniel, Bessemer Steel Works, Sheffield.
1865. **Alleyne**, John Gay Newton, Butterley Iron Works, Alfreton.
1867. **Allibon**, George, Rosherville Iron Works, Northfleet, near Gravesend.
1859. **Alton**, George, Midland Road, Derby.
1861. **Amos**, Charles Edwards, 5 Cedars Road, Clapham Common, London, S.W.
1867. **Amos**, James Chapman, Grove Works, Southwark Street, London, S.E.
1856. **Anderson**, John, Superintendent of Machinery to the War Department, Royal Arsenal, Woolwich, S.E.
1856. **Anderson**, William, Erith Iron Works, Erith, Kent, S.E.
1862. **Angus**, Robert, Locomotive Superintendent, North Staffordshire Railway, Stoke-upon-Trent.
1858. **Appleby**, Charles Edward, Renishaw Colliery, near Chesterfield.
1867. **Appleby**, Charles James, Emerson Street, Southwark, London, S.E.
1859. **Armitage**, William James, Farnley Iron Works, Leeds.
1866. **Armstrong**, George, Great Western Railway, Locomotive Department, Wolverhampton.
1863. **Armstrong**, John, Timber Works, 17 North Bridge Street, Sunderland.
1857. **Armstrong**, Joseph, Locomotive Superintendent, Great Western Railway, Swindon.
1858. **Armstrong**, Sir William George, Elswick, Newcastle-on-Tyne.
1857. **Ashbury**, James Lloyd, 9 Sussex Place, Hyde Park Gardens, London, W.

1865. Bagshawe, John J., Thames Steel Works, Sheffield.
1865. Bailey, John, Blackhall Place Iron Works, Dublin.
1860. Bailey, Samuel, Mining Engineer, The Pleck, near Walsall.
1866. Baines, William, London Works, Soho, near Birmingham.
1866. Baker, Samuel, 22 Oil Street, Liverpool.
1865. Baldwin, Martin, Bovereux Iron Works, Bilston.
1860. Barclay, John, Bowling Iron Works, near Bradford, Yorkshire.
1865. Barclay, William, 4 College Lane, Liverpool.
1866. Barker, George, Messrs. Barker and Cope, Kidsgrove, Stoke-upon-Trent.
1860. Barker, Paul, Old Park Iron Works, Wednesbury.
1866. Barnard, Clement, 11 Billiter Square, London, E.C.
1862. Barrow, Joseph, Whalley Chambers, 88 King Street, Manchester.
1867. Barrows, Thomas Welch, Portable Engine Works, Banbury.
1862. Barton, Edward, Carnforth Hæmatite Iron Works, Carnforth, near Lancaster.
1865. Bass, William, Sanitary Pipe Works, Parkgate, near Rotherham.
1860. Batho, William Fothergill, 36 Lancaster Street, Birmingham.
1859. Beacock, Robert, Victoria Foundry, Leeds.
1865. Beardshaw, Charles C., Baltic Steel Works, Sheffield.
1848. Beattie, Joseph, Locomotive Superintendent, London and South Western Railway, Nine Elms, London, S.W.
1867. Beaumont, Captain Frederick, R.E., Royal Engineer Office, Sheerness.
1859. Beck, Edward, Messrs. Neild and Co., Dallam Iron Works, Warrington. (*Life Member.*)
1862. Beckett, Henry, Mining Engineer, Upper Penn, Wolverhampton.
1864. Beckton, James George, Whitby, Yorkshire.
1865. Bell, Charles, North Staffordshire Railway, Locomotive Department, Stoke-upon-Trent.
1867. Bell, George, Soho Iron Works, Bolton.
1858. Bell, Isaac Lowthian, Clarence Felling and Wylam Iron Works, Newcastle-on-Tyne.
1865. Bell, John, Addison Villa, Timperley, near Manchester.
1857. Bellhouse, Edward Taylor, Eagle Foundry, Hunt Street, Oxford Street, Manchester.
1868. Belliss, George Edward, Agricultural Engine Works, Broad Street, Birmingham.
1865. Bennett, Henry, Hadley Lodge, near Wellington, Shropshire.
1854. Bennett, Peter Duckworth, Spon Lane Iron Foundry, Westbromwich.
1865. Benson, George Henry, Stalybridge.
1867. Berkley, George, 9 Victoria Chambers, Victoria Street, Westminster, S.W.
1867. Bernhardt, George, Stand Lane, Radcliffe, near Manchester.
1861. Bessemer, Henry, 4 Queen Street Place, New Cannon Street, London, E.C.

Bevis, Restel Ratsey, Birkenhead Iron Works, Birkenhead.

Beyer, Charles F., Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

Binns, Charles, Mining Engineer, Clay Cross, near Chesterfield.

Birckel, John James, Regent's Canal Iron Works, Eagle Wharf Road, London, N.

Birkbeck, John Addison, Sheepbridge Iron Works, Chesterfield.

Birley, Henry, Haigh Foundry, near Wigan.

Blackburn, Isaac, Witton Park Iron Works, Darlington.

Blackwell, Samuel Holden, Dudley.

Bladen, Charles, Provan Mill House, Springburn, near Glasgow.

Blake, Henry Wollaston, Messrs. James Watt and Co., 18 London Street, London, E.C.

Bleckly, John James, Bewsey Iron Works, Warrington.

Blyth, Alfred, Steam Engine Works, Fore Street, Limehouse, London, E.

Boeddinghaus, Julius, Messrs. Heinrich Boeddinghaus and Sons, Elberfeld, Prussia.

Bouch, Thomas, 78 George Street, Edinburgh.

Bouch, William, Shildon Engine Works, Darlington.

Bovill, George Hinton, 24 Duke Street, Westminster, S.W.

Bower, John Wilkes, Lancashire and Yorkshire Railway, Engineer's Office, Manchester. (*Life Member.*)

Boyd, Nelson, Belfast Foundry, Donegal Street, Belfast.

Bragge, William, Atlas Steel and Iron Works, Sheffield.

Bramwell, Frederick Joseph, 37 Great George Street, Westminster, S.W.

Breeden, Joseph, 156 Cheapside, Birmingham.

Broad, Robert, Horseley Iron Works, near Tipton.

Brock, Walter, Vulcan Foundry, Glasgow.

Brogden, Henry, Sale, near Manchester. (*Life Member.*)

Brown, Andrew Betts, 80 Cannon Street, London, E.C.

Brown, Charles James, Unity Chambers, Temple Street, Birmingham.

Brown, George, Rotherham Iron Works, Rotherham.

Brown, Henry, Metropolitan Carriage and Wagon Co., Saltley Works, Birmingham.

Brown, James, Jun., Messrs. James Watt and Co., Soho Foundry, near Birmingham.

Brown, Sir John, Atlas Steel and Iron Works, Sheffield.

Brown, Ralph, Patent Shaft Works, Wednesbury.

Bruce, William Duff, Executive Engineer, Presidency Division, Calcutta, India.

Bryant, Frederick William, Blackfriars Bridge Works, Chatham Place, London, E.C.

1866. Bryham, William, Rose Bridge and Douglas Bank Collieries, near Wigan.
1868. Buckton, George, Well House Foundry, Leeds.
1858. Burn, Henry, Midland Railway, Locomotive Department, Derby.
1856. Butler, Ambrose Edmund, Kirkstall Forge, Leeds.
1863. Butler, Arthur, Surdah, Radshye, Lower Bengal, India: (or care of W. J. Butler, Chipping Hill, Witham.)
1859. Butler, John, Stanningley Iron Works, near Leeds.
1859. Butler, John Octavius, Kirkstall Forge, Leeds.

1857. Cabry, Joseph, Resident Engineer, Blyth and Tyne Railway, Newcastle-on-Tyne.
1847. Cabry, Thomas, North Eastern Railway, York.
1847. Cammell, Charles, Cyclops Steel and Iron Works, Sheffield.
1867. Campbell, Daniel, 10 John Street, Adelphi, London, W.C.
1864. Campbell, David, 20 Castle Street, Liverpool.
1864. Campbell, James, Staveley Coal and Iron Works, Staveley, near Chesterfield.
1860. Cannell, Fleetwood James, Atlas Steel and Iron Works, Sheffield.
1860. Carbutt, Edward Hamer, Vulcan Iron Works, Thornton Road, Bradford, Yorkshire.
1865. Carlton, Samuel, Great Western Railway, Locomotive Department, Swindon.
1866. Carpmael, William, 24 Southampton Buildings, London, W.C.
1856. Carrett, William Elliott, Sun Foundry, Leeds.
1868. Carrington, Thomas, Jun., Mining Engineer, Kiveton Park Colliery, near Sheffield.
1864. Carrington, William Thomas, 10 Park Street, Westminster, S.W.
1858. Carson, James Irving, Locomotive Superintendent, West Hartlepool Harbour and Railway, Stockton-on-Tees.
1866. Chapman, Henry, 41 Boulevard Malesherbes, Paris.
1867. Chatwood, Samuel, Lancashire Safe and Lock Works, Bolton.
1857. Chrimes, Richard, Brass Works, Rotherham.
1866. Claridge, Thomas, Phœnix Foundry, near Bilston.
1859. Clark, George, Monkwearmouth Engine Works, Sunderland.
1867. Clark, George, Jun., Monkwearmouth Engine Works, Sunderland.
1862. Clark, James, Wellington Foundry, Leeds.
1867. Clark, William, Engineer to the Municipality of Calcutta, 9 Victoria Chambers, Victoria Street, Westminster, S.W.
1865. Clarke, John, Railway Foundry, Jack Lane, Leeds.
1859. Clay, William, Exchange Buildings, Liverpool.
1863. Clayton, Robert, Soho Foundry, Preston.
1866. Cleworth, Charles, Assistant Locomotive Superintendent, East Indian Railway, Jumalpore, India.
1867. Cliff, Joseph, Union Foundry, Bradford, Yorkshire.

Clift, John Edward, Prospect Hill, Redditch.
Clunes, Thomas, Worcester Engine Works, Worcester.
Cochrane, Charles, Woodside Iron Works, near Dudley.
Cochrane, Henry, Ormesby Iron Works, Middlesbrough.
Cochrane, John, Woodside Iron Works, near Dudley.
Cochrane, William, Mining Engineer, Elswick Colliery, Elswick, Newcastle-on-Tyne.
Cockey, Francis Christopher, Selwood Iron Works, Frome.
Coddington, William, Ordnance Cotton Mill, Blackburn.
Coke, Richard George, Mining Engineer, Chesterfield.
Coke, William Langton, 11 Great Queen Street, Westminster, S.W.
Colburn, Zerah, 7 Gloucester Road, Regent's Park, London, N.W.
Cooper, Samuel Thomas, Leeds Iron Works, Leeds.
Cope, James, Mining Engineer, Pensnett, near Dudley.
Corlett, Henry Lee, Great Southern and Western Railway, Carriage Department, Dublin.
Corry, Edward, 8 New Broad Street, London, E.C.
Cortazzi, Francis James, care of Hugh Hornby, Sandown, Wavertree, Liverpool.
Coulson, William, Mining Engineer, Shamrock House, Durham.
Coulthard, Hiram Craven, Park Iron Works, Blackburn.
Cowans, John, St. Nicholas and Woodbank Iron Works, Carlisle.
Cowper, Edward Alfred, 6 Great George Street, Westminster, S.W.
Cox, Samuel H. F., Board of Health Office, Brynmawr, near Tredegar.
Crampton, Thomas Russell, 12 Great George Street, Westminster, S.W.
Craven, William, Vauxhall Iron Works, Osborne Street, Manchester.
Crawhall, Joseph, St. Ann's Wire and Hemp Rope Works, Newcastle-on-Tyne.
Cross, James, St. Helen's Locomotive Works, St. Helen's.
Crow, George, Messrs. R. Stephenson and Co., Newcastle-on-Tyne.
Crowe, Edward, Tees Side Iron Works, Middlesbrough.

Daglish, George Heaton, St. Helen's Foundry, St. Helen's.
Daniel, Edward Freer, Caerphilly Foundry, Cardiff.
Daniel, William, 11 Blenheim Square, Leeds.
Darby, Abraham, Ebbw Vale Iron Works, near Tredegar.
Darby, Charles E., Brymbo Iron Works, near Wrexham.
Davidson, James, Royal Arsenal, Laboratory Department, Woolwich, S.E.
Davies, Benjamin, Huyton Bleach Works, near Chorley.
Davis, Henry Wheeler, Resident Engineer, Great Eastern Railway, Stratford, London, E.
Davy, Alfred, Park Iron Works, Sheffield.

1849. Dawes, George, Milton and Elsecar Iron Works, near Barnsley.
1860. Dawes, William Henry, Bromford Iron Works, Westbromwich.
1861. Dawson, Benjamin, South Hetton, near Fence Houses.
1868. Dean, William, Great Western Railway, Locomotive Department, Swindon.
1866. Death, Ephraim, Albert Works, Leicester.
1857. De Bergue, Charles, Strangeways Iron Works, Manchester.
1858. Dees, James, Whitehaven.
1858. Dempsey, William, 26 Great George Street, Westminster, S.W.
1868. Derham, John J., Machine Works, Pleasanton, near Blackburn.
1864. Dewhurst, John, Lancashire Steel Works, Gorton, Manchester.
1865. Dircks, Henry, 48 Charing Cross, London, S.W. (*Life Member.*)
1859. Dixon, John, Railway Foundry, Bradford, Yorkshire.
1865. Dobson, Benjamin, Messrs. Dobson and Barlow, Kay Street Works, Bolton.
1868. Dodman, Alfred, St. James's Works, Lynn.
1865. Domville, Charles Kelloch, Resident Engineer and Locomotive Superintendent, Belfast and County Down Railway, Belfast.
1865. Douglas, Charles P., Consett Iron Works, near Blackhill, County Durham.
1857. Douglas, George K., Messrs. R. Stephenson and Co., Newcastle-on-Tyne.
1857. Dove, George, St. Nicholas and Woodbank Iron Works, Carlisle.
1866. Downey, Alfred C., Ormesby Iron Works, Middlesbrough.
1847. Dübs, Henry, Glasgow Locomotive Works, Glasgow.
1857. Dunlop, John Macmillan, Holehird, Windermere.
1854. Dunn, Thomas, 52 Withington Street, Pendleton, Manchester.
1864. Dunn, Thomas Edward, care of Messrs. Bird and Co., Allahabad, India: (or care of R. Dunn, Howick, Bilton, Northumberland.)
1861. Dutton, Charles, Sams Lane, Westbromwich.
1860. Dyson, George, Tudhoe Iron Works, near Ferryhill.
1865. Dyson, Robert, Phœnix Wheel Tyre and Axle Works, Rotherham.

1859. Eassie, Peter Boyd, Railway Saw Mills, Gloucester.
1858. Easton, Edward, Grove Works, Southwark Street, London, S.E.
1867. Easton, James, Mining Engineer, Nest House, Gateshead.
1856. Eastwood, James, Railway Iron Works, Derby.
1868. Eddison, Robert William, Steam Plough and Locomotive Works, Leeds.
1866. Elce, John, Phœnix Iron Works, Jersey Street, Manchester.
1859. Elliot, George, M.P., Houghton-le-Spring, near Fence Houses.
1865. Elliot, Walter, Civil Engineer to the Colonial Government, Gibraltar.
1860. Elwell, Thomas, Messrs. Varrall Elwell & Poulot, 9 Avenue Trudaine, Paris.
1853. England, George, Hatcham Iron Works, London, S.E.
1861. Esson, William, Engineer, Cheltenham Gas Works, Cheltenham.
1864. Etienne, Antonin, 77 Calle de las Palmas, Seville, Spain.
1857. Evans, John Campbell, care of George W. Evans, 5 Wright Street, Hull.

veritt, George Allen, Kingston Metal Works, Adderley Street, Birmingham.
veritt, William Edward, Kingston Metal Works, Adderley Street, Birmingham.
vers, Frank, Cradley Iron Works, near Stourbridge.

airbairn, Sir Andrew, Wellington Foundry, Leeds.
airlie, Robert Francis, 9 Victoria Chambers, Victoria Street, Westminster, S.W.
ardon, Thomas, Linslade Iron Works, Leighton Buzzard.
aviell, Samuel Clough, Clarence Iron Works, Leeds.
enby, Joseph Beverley, 61 Pershore Road, Edgbaston, Birmingham.
ernie, John, Clarence Iron Works, Leeds.
iddes, Walter, Engineer, Bristol United Gas Works, Bristol.
ield, Edward, Chandos Chambers, Buckingham Street, Adelphi, London, W.C.
ield, Joshua, 110 Westminster Bridge Road, Lambeth, London, S.E.
illiter, Edward, Resident Engineer, Leeds Water Works, 16 East Parade, Leeds.
irth, Arthur, Leeds Iron Works, Leeds.
irth, Samuel, 14 Springfield Mount, Leeds.
leet, Thomas, Crown Boiler Works, Westbromwich.
leetwood, Daniel Joseph, 58 Broad Street, Birmingham.
letcher, Edward, Locomotive Superintendent, North Eastern Railway, Gateshead.
letcher, Henry Allason, Lowca Engine Works, Whitehaven. (*Life Member.*)
letcher, James, Messrs. W. Collier and Co., 2 Greengate, Salford, Manchester.
letcher, James, Jun., Messrs. W. Collier and Co., 2 Greengate, Salford, Manchester.
letcher, Lavington Evans, Association for the Prevention of Steam Boiler Explosions, 41 Corporation Street, Manchester.
ogg, Robert, 17 Park Street, Westminster, S.W.
orster, Edward, Spon Lane Glass Works, near Birmingham.
orster, John, Messrs. Westray and Forster, Barrow-in-Furness, Lancashire.
orsyth, John C., North Staffordshire Railway, Stoke-upon-Trent.
oster, Edward Henry, Lecourt, Petersfield.
oster, Sampson Lloyd, Old Park Hall, Walsall.
othergill, Benjamin, 139 Cannon Street, London, E.C.
owler, George, Hucknall Torkard Collieries, near Nottingham.

1847. Fowler, John, 2 Queen Square Place, Westminster, S.W.

1847. Fox, Sir Charles, 8 New Street, Spring Gardens, London, S.W.

1866. Fox, Charles Douglas, 8 New Street, Spring Gardens, London, S.W.

1859. Fraser, John, 18 York Place, Leeds.

1866. Fraser, John Simpson, Carriage and Wagon Superintendent, Great Western Railway, Paddington, London, W.

1856. Freeman, Joseph, 98 Cannon Street, London, E.C.

1864. Frost, Thomas, Wadsley Bridge Iron and Steel Works, near Sheffield.

1852. Froude, William, Elmsleigh, Paignton, South Devon.

1866. Fry, Albert, Bristol Wagon Works, Temple Gate, Bristol.

1865. Gainsford, William Dunn, Sheffield Coal Co., Sheffield.

1866. Galloway, Charles John, Knott Mill Iron Works, Manchester.

1862. Galton, Capt. Douglas, R.E., War Office, Pall Mall, London, S.W.

1847. Garland, William S., Messrs. James Watt and Co., Soho Foundry, near Birmingham.

1867. Gauntlett, William Henry, Middlesbrough.

1848. Gibbons, Benjamin, The Leasowes, near Birmingham.

1856. Gilkes, Edgar, Tees Engine Works, Middlesbrough.

1866. Gilroy, George, Engineer, Ince Hall Colliery, Wigan.

1862. Godfrey, Samuel, Messrs. Bolckow and Vaughan's Iron Works, Middlesbrough.

1867. Gooch, William Frederick, Vulcan Foundry, Warrington.

1865. Göransson, Göran Fredrick, Steel Works, Gefle and Högbo, Sweden.

1865. Gray, John McFarlane, Board of Trade Steam Ship Surveyor, Custom House, Dublin.

1861. Green, Edward, Jun., Phœnix Works, Wakefield.

1867. Greenwell, George Clementson, Mining Engineer, Poynton, near Stockport.

1858. Greenwood, Thomas, Albion Works, Armley Road, Leeds.

1857. Gregory, John, 57 Millbank Street, Westminster, S.W.

1865. Greig, David, Steam Plough and Locomotive Works, Leeds.

1866. Grice, Edwin James, Stour Valley Works, Spon Lane, Westbromwich.

1860. Grice, Frederic Groom, Cwmbran Nut and Bolt Works, near Newport, Monmouthshire.

1868. Grierson, Henry Houldsworth, St. George's Iron Works, Hulme, Manchester.

1866. Gurden, Charles Frederick, Superintendent Engineer, Brasil and River Plate Steam Boat Co., 43 Canning Street, Birkenhead.

1863. Hackney, William, 3 Great George Street, Westminster, S.W.

1861. Haggie, Peter, Hemp and Wire Rope Works, Gateshead.

1863. Hall, Joseph, Gratz Iron Works, Gratz, Styria, Austria.

1857. Hall, William, 167 Dartmouth Street, Birmingham.

1860. Hamilton, Gilbert, Messrs. James Watt and Co., Soho Foundry, near Birmingham.

1858. Harding, John, Beeston Manor Iron Works, Leeds.

1859. Harman, Henry William, Canal Street Works, Manchester.

1856. Harrison, George, Canada Works, Birkenhead.

1858. Harrison, Thomas Elliot, 1 Westminster Chambers, Victoria Street, Westminster, S.W.

1865. Harrison, William, Bank Foundry, Blackburn.

1865. Harrison, William Arthur, Cambridge Street Works, Manchester.

1858. Haswell, John A., North Eastern Railway, Locomotive Department, Gateshead.

1857. Haughton, S. Wilfred, Greenbank, Carlow. (*Life Member.*)

1861. Hawkins, William Bailey, 2 Suffolk Lane, Cannon Street, London, E.C.

1856. Hawksley, Thomas, 30 Great George Street, Westminster, S.W.

1848. Hawthorn, William, Messrs. Hawthorn and Co., Newcastle-on-Tyne.

1862. Haynes, Thomas John, Calpe Foundry, North Front, Gibraltar.

1860. Head, John, Messrs. Ransomes and Sims, Orwell Works, Ipswich.

1853. Headly, James Ind, Eagle Foundry, Mill Road, Cambridge.

1857. Healey, Edward Charles, 163 Strand, London, W.C.

1863. Heath, William J. W., Soane Irrigation Works, Baroon, Dehree on Soane, Grand Trunk Road, Shahabad, India: (or care of John J. Heath, 67 Great Charles Street, Birmingham.)

1864. Heathfield, Richard, Lion Galvanising Works, Birmingham Heath, Birmingham.

1860. Heaton, George, Royal Copper Mint, Icknield Street East, Birmingham.

1868. Heaton, John, Langley Mill Steel and Iron Works, near Nottingham.

1865. Hetherington, John Muir, Vulcan Works, Pollard Street, Manchester.

1866. Hetherington, Thomas Ridley, Vulcan Works, Pollard Street, Manchester.

1864. Hetherington, William Isaac, Vulcan Works, Pollard Street, Manchester.

1865. Hewett, Edward Edwards, Yorkshire Engine Co., Meadow Hall Works, near Sheffield.

1866. Hickman, George Haden, Groveland Iron Works, Dudley Port, Tipton.

1864. Hide, Thomas C., 46 Fenchurch Street, London, E.C.

1863. Hind, Roger, Scotland Bank Iron Works, Warrington.

1866. Hodgson, Charles, 163 Strand, London, W.C.

1858. Hodgson, Robert, North Eastern Railway, Newcastle-on-Tyne.

1852. Holcroft, James, Norton, near Stourbridge.

1866. Holcroft, Thomas, Bilston Foundry, Bilston.

1865. Holliday, John, Messrs. Bethell's Creosote Works, Westbromwich.

1863. Holt, Francis, Gorton Foundry, Manchester.

1867. Holt, William Lyster, 6 Storey's Gate, Westminster, S.W.

1867. Homer, Charles James, Mining Engineer, Chatterley Ironstone Works, Tunstall, near Stoke-upon-Trent.

1848. Homersham, Samuel Collett, 19 Buckingham Street, Adelphi, London, W.C.

1860. Hopkins, James Innes, 95 Cannon Street, London, E.C.

1866. Hopkins, John Satchell, Tinplate Works, Granville Street, Birmingham.

1856. Hopkinson, John, London Road Iron Works, Manchester.

1867. Hopper, William, Machine Works, Moscow, Russia.

1867. Horrocks, Samuel, 51 King Street, Manchester.

1868. Horsley, Thomas, Jun., Alfreton Iron Works, Alfreton.

1858. Horsley, William, Jun., Whitehill Point Iron Works, Percy Main, near Newcastle-on-Tyne.

1868. Horton, Enoch, Alma Works, Darlaston, near Wednesbury.

1851. Horton, Joshua, Ætna Works, Smethwick, near Birmingham.

1867. Horton, Thomas Ellwood, Lilleshall Iron Works, Oakengates, near Wellington, Shropshire.

1858. Hosking, John, Gateshead Iron Works, Gateshead.

1866. Houghton, John Campbell Arthur, Woodside Iron Works, near Dudley.

1864. Howard, Eliot, 84 Upper Whitecross Street, London, E.C.

1860. Howard, James, M.P., Britannia Iron Works, Bedford.

1867. Howard, Robert Luke, 84 Upper Whitecross Street, London, E.C.

1860. Howe, William, Clay Cross Coal and Iron Works, near Chesterfield.

1861. Howell, Joseph Bennett, Hartford Steel Works, Sheffield.

1866. Hoyle, William Jennings, Messrs. Whitworth and Co., Chorlton Street, Manchester.

1868. Hudswell, William Shillito, Railway Foundry, Jack Lane, Leeds.

1867. Hughes, George Douglas, Queen's Foundry, London Road, Nottingham.

1864. Hulse, William Wilson, Whalley Chambers, 88 King Street, Manchester.

1859. Hunt, James P., Corngreaves Iron Works, near Birmingham.

1856. Hunt, Thomas, care of the Secretary, Westminster Palace Hotel, London, S.W.

1864. Hutchinson, Edward, Skerne Iron Works, Darlington.

1863. Hutton, Walter Stuart, Prospect Works, Hunslet Lane, Leeds.

1865. Hyde, Lt.-Colonel Henry, R.E., Master of the Mint, Calcutta, India: (or care of Rev. H. M. C. Hyde, 14 Grove Lane, Camberwell, London, S.E.) (*Life Member.*)

1867. Inglis, William, Soho Iron Works, Bolton.

1866. Ireland, William, 41 Beech Lane, Macclesfield.

1865. Jackson, John, Stibbington House, Wansford.

1859. Jackson, Matthew Murray, Engineer-in-Chief, Imperial Danube Steam Navigation Works, Pesth, Austria.

kson, Peter Rothwell, Salford Rolling Mills, Manchester.
kson, Robert, Ætna Steel Works, Sheffield.
kson, Samuel, Cyclops Steel and Iron Works, Sheffield.
ger, Herrmann Frederic, Gorton Foundry, Manchester.
frey, George William, Hartlepool Iron Works, Hartlepool.
nes, Jabez, 40 Prince's Street, Commercial Road, Lambeth, London, S.E.
nes, John, Ebbw Vale Iron Works, near Tredegar.
cock, Thomas William, Mining Engineer, 18 Bank Street, Sheffield.
freys, Edward A., Low Moor Iron Works, near Bradford, Yorkshire.
sop, Thomas, Park Steel Works, Sheffield.
son, John, Derwent Foundry, Derby.
son, Robert, Phœnix Works, Dudley.
nson, Bryan, Flookersbrook Foundry, Chester.
nson, James, North Staffordshire Railway, Engineer's Office, Stoke-upon-Trent.
nson, Samuel Waite, Locomotive Superintendent, Great Eastern Railway, Stratford, London, E.
es, Edward, The Larches, Handsworth, near Birmingham.
es, Hodgson, 67 Victoria Street, Westminster, S.W.

, James Clarkson, Phœnix Foundry, Bury, Lancashire.
lett, John, 2 Newshams Buildings, King Street, Wigan.
dall, William, Locomotive Superintendent, Blyth and Tyne Railway, Percy Main, near Newcastle-on-Tyne.
nan, James, Agricultural Implement Works, 19 Fishamble Street, Dublin.
nedy, James, Cressington Park, Aigburth, Liverpool.
nedy, Lt.-Colonel John Pitt, Engineer, Bombay Baroda and Central Indian Railway; 45 Finsbury Circus, London, E.C.
nedy, John Pitt, Bombay Baroda and Central Indian Railway; 45 Finsbury Circus, London, E.C.
nedy, Thomas Stuart, Wellington Foundry, Leeds.
r, Peter, Thread Works, New Street, Paisley.
shaw, John, 24 Duke Street, Westminster, S.W.
ball, Frederick James, 35 South Third Street, Philadelphia, Pennsylvania, United States.
kaldy, David, Testing and Experimental Works, The Grove, Southwark Street, London, S.E.
tley, Matthew, Locomotive Superintendent, Midland Railway, Derby.
tley, William, Midland Railway, Locomotive Department, Derby.
son, Frederick William, Monkbridge Iron Works, Leeds.
son, James, Airedale Foundry, Leeds.

1859. Kitson, James, Jun., Monkbridge Iron Works, Leeds.
1868. Kitson, John Hawthorn, Airedale Foundry, Leeds.
1866. Knap, Conrad, Star Tube Works, Heneage Street, Birmingham.
1863. Knight, Thomas, 130 Bradford Street, Birmingham.

1866. Lambert, William Blake, Berwick-upon-Tweed.
1867. Lancaster, Charles William, Gun Manufactory, 151 New Bond Street, London, W.
1863. Lancaster, John, M.P., Kirkless Hall Coal and Iron Works, near Wigan.
1860. Law, David, Phoenix Iron Works, Glasgow.
1867. Lawrence, Henry, The Grange Iron Works, Durham.
1857. Laybourn, John, Isca Foundry, Newport, Monmouthshire.
1856. Laybourn, Richard, Rhymney Iron Works, Tredegar.
1860. Lea, Henry, 35 Paradise Street, Birmingham.
1868. Lea, John, Bowling Iron Works, near Bradford, Yorkshire.
1865. Ledger, Joseph, West Cumberland Hæmatite Iron Works, Workington.
1862. Lee, J. C. Frank, 22 Great George Street, Westminster, S.W.
1863. Lees, Samuel, Jun., Park Bridge Iron Works, Ashton-under-Lyne.
1863. Leigh, Evan, Junction Works, Miles Platting, Manchester.
1865. Leigh, Frederick Allen, Junction Works, Miles Platting, Manchester.
1866. Leigh, Joseph D., Ellesmere Foundry, Patricroft, near Manchester.
1858. Leslie, Andrew, Iron Ship Building Yard, Hebburn Quay, Gateshead.
1860. Lewis, Thomas William, Abercanaid House, Merthyr Tydvil.
1864. Lindsley, George, Great Western Railway, Locomotive Department, Swindon.
1856. Linn, Alexander Grainger, 2 Queen Square Place, Westminster, S.W.
1857. Little, Charles, Staveley Coal and Iron Works, Staveley, near Chesterfield.
1866. Little, George, Hartford Iron Works, Oldham.
1867. Livesey, James, 9 Victoria Chambers, Victoria Street, Westminster, S.W.
1867. Lloyd, Charles, 6 Westminster Chambers, Victoria Street, Westminster, S.W.
1863. Lloyd, Edward R., Albion Tube Works, Nile Street, Birmingham.
1854. Lloyd, George Braithwaite, Messrs. Lloyds, High Street, Birmingham. (*Life Member.*)
1862. Lloyd, John, Lilleshall Iron Works, Oakengates, near Wellington, Shropshire.
1866. Lloyd, Joseph Foster, Darlaston Green Iron and Steel Works, near Wednesbury.
1847. Lloyd, Sampson, Old Park Iron Works, Wednesbury.
1864. Lloyd, Sampson Zachary, Old Park Iron Works, Wednesbury.
1852. Lloyd, Samuel, Old Park Iron Works, Wednesbury.
1862. Lloyd, Wilson, Moor Hall, Sutton Coldfield, near Birmingham.
1863. Loam, Matthew Hill, Engineer, Gas and Water Works, Nottingham.

Longridge, Robert Bewick, Steam Boiler Assurance Company, 67 King Street, Manchester.
Longridge, William Smith, Alderwasley Iron Works, Ambergate, near Derby.
Lord, Edward, Canal Street Works, Todmorden.
Lord, Thomas Wilks, Bank Mills, Leeds.
Low, George, St. Peter's Iron Works, Ipswich.
Lundh, Sverier Hakon, 8 Lille Strandgade, Christiania, Norway: (or 9B New Broad Street, London, E.C.)
Lynde, James Gascoigne, Town Hall, Manchester.
Lyndon, George Frederick, Minerva Works, Fazeley Street, Birmingham.

Macfarlane, Walter, Saracen Foundry, Glasgow.
Mackay, John, Mount Hermon, Drogheda.
Macnab, Archibald Francis, Peninsular and Oriental Steam Navigation Co., Hong-Kong, China: (or care of P. and O. S. N. Co., 122 Leadenhall Street, London, E.C.)
MacNay, William, Shildon Engine Works, Darlington.
Macnee, Daniel, Brinsworth Iron and Steel Works, Rotherham.
Mallet, Robert, 7 Westminster Chambers, Victoria Street, Westminster, S.W.
Manning, John, Boyne Engine Works, Hunslet, Leeds.
Mansell, Richard Christopher, South Eastern Railway, Carriage Department, Ashford.
Mappin, Frederick Thorpe, Sheaf Works, Sheffield.
March, George, Union Foundry, Dewsbury Road, Leeds.
Markham, Charles, Staveley Coal and Iron Works, Staveley, near Chesterfield.
Marshall, Francis Carr, Jarrow Engine Works, Quayside, Newcastle-on-Tyne.
Marshall, James, North Eastern Railway, Carlisle.
Marshall, William Ebenezer, Sun Foundry, Leeds.
Marshall, William Prime, 81 Newhall Street, Birmingham.
Marten, Edward Bindon, Engineer, Stourbridge Water Works, 56 Hagley Street, Stourbridge.
Marten, Henry John, Parkfield Iron Works, near Wolverhampton.
Martin, William, Messrs. W. Martin Fils et Cie., 43 Rue d'Elbeuf, Rouen, France.
Martindale, Lt.-Colonel Ben Hay, R.E., Controllor, Montreal, Canada.
Martineau, Francis Edgar, Globe Works, Cliveland Street, Birmingham.
Martley, William, Locomotive Superintendent, London Chatham and Dover Railway, Longhedge Works, Wandsworth Road, London, S.W.
Masselin, Armand, 14 Rue de Lancry, Paris.

1867. Mather, William, Salford Iron Works, Manchester.

1853. Mathews, William, North Grove, Great Malvern.

1848. Matthew, John, 13 Park Street, Park Lane, London, W.

1847. Matthews, William Anthony, Sheaf Works, Sheffield.

1853. Maudslay, Henry, Bystock, near Exmouth. (*Life Member.*)

1864. Maudslay, Thomas Henry, 110 Westminster Bridge Road, Lambeth, London, S.E.

1861. May, Robert Charles, 6 Great George Street, Westminster, S.W.

1857. May, Walter, Suffolk Works, Berkley Street, Birmingham.

1865. Maylor, John, 11 Commerce Chambers, Lord Street, Liverpool.

1859. Maylor, William, Calicut, Madras, India.

1847. McClean, John Robinson, M.P., 23 Great George Street, Westminster, S.W.

1865. McDonnell, Alexander, Locomotive Superintendent, Great Southern and Western Railway, Dublin.

1867. McEwen, James, Wordsley Foundry, Stourbridge.

1864. McEwen, Lawrence Thompson, Glaisdale Iron Works, near Yarm.

1868. McKay, Benjamin, Small Arms Factory, Small Heath, near Birmingham.

1860. McKenzie, James, Well House Foundry, Leeds.

1859. McKenzie, John, Worcester Engine Works, Worcester.

1863. Meek, Sturges, Resident Engineer, Lancashire and Yorkshire Railway, Manchester.

1858. Meik, Thomas, Engineer to the River Wear Commissioners, Sunderland.

1857. Menelaus, William, Dowlais Iron Works, Merthyr Tydvil.

1866. Meredith, Alban, 96 Newgate Street, London, E.C.

1867. Merryweather, Richard M., 63 Long Acre, London, W.C.

1857. Metford, William Ellis, Flook House, Taunton.

1847. Middleton, William, Vulcan Iron Foundry, Summer Lane, Birmingham.

1862. Miers, Francis C., Stoneleigh Lodge, Grove Road, Clapham Park, London, S.W.

1864. Miers, John William, 74 Addison Road, Kensington, London, W.

1862. Millward, John, 27 Paradise Street, Birmingham.

1856. Mitchell, Charles, The Grange, Surbiton Hill, Kingston-on-Thames.

1861. Mitchell, Joseph, Worsbrough Dale Colliery, near Barnsley.

1859. Moor, William, Engineer, Hetton Colliery, Hetton, near Fence Houses.

1864. Moore, Sampson, North Foundry, Cotton Street, Clarence Dock, Liverpool.

1864. Morgan, Joshua Llewelyn, Kingscombe, near Cowbridge.

1867. Morgans, Thomas, Foundry and Wagon Works, Pontypool.

1868. Morris, William, Waldridge Colliery, Chester-le-Street, near Fence Houses.

1849. Morrison, Robert, Brotton Grange, Saltburn-by-the-Sea, Yorkshire.

1865. Morton, Robert, Alliance Chambers, Borough, London, S.E.

1865. Mosse, James Robert, Mauritius Railways, Port Louis, Mauritius.

1858. Mountain, Charles George, Suffolk Works, Berkley Street, Birmingham.

1866. Muir, Andrew, Victoria Bridge Works, Salford, Manchester.
1863. Muir, William, 57 Claverton Street, Pimlico, London, S.W.
1865. Murdock, William Mallabey, Barrow Hæmatite Steel Works, Barrow-in-Furness, Lancashire.
1859. Murphy, James, Railway Works, Newport, Monmouthshire.
1858. Murray, Thomas H., Engine Works, Chester-le-Street, near Fence Houses.
1863. Musgrave, John, Jun., Globe Iron Works, Bolton.

1848. Napier, John, Vulcan Foundry, Glasgow.
1867. Napier, John D., Kilmun House, Holt Hill, Birkenhead.
1856. Napier, Robert, West Shandon, Helensburgh, near Glasgow. (*Life Member.*)
1861. Naylor, John William, Wellington Foundry, Leeds.
1858. Naylor, William, Great Indian Peninsula Railway, 3 New Broad Street, London, E.C.
1863. Neilson, Walter Montgomerie, Hyde Park Locomotive Works, Glasgow.
1860. Nettlefold, Joseph Henry, Screw Works, Broad Street, Birmingham.
1866. Newdigate, Albert Lewis, Byrkley Lodge, near Burton-on-Trent.
1862. Newton, William Edward, 66 Chancery Lane, London, W.C.
1858. Nichol, Peter Dale, care of Anthony Nichol, 19 Quay, Newcastle-on-Tyne.
1866. Norfolk, Richard, Beverley Iron and Wagon Works, Beverley.
1850. Norris, Richard Stuart, 272 Upper Parliament Street, Liverpool.
1868. Norris, William Gregory, Coalbrookdale Iron Works, near Wellington, Shropshire.

1868. O'Connor, Charles, Newark Foundry, Bath.
1866. Oliver, William, Victoria Foundry, Chesterfield.
1867. Olrick, Lewis, 27 Leadenhall Street, London, E.C.
1864. Ommanney, Frederick Francis, New Bridge Foundry, Adelphi Street, Salford, Manchester.
1867. Oughterson, George Blake, Messrs. W. Martin Fils et Cie., 43 Rue d'Elbeuf, Rouen, France.
1847. Owen, William, Phœnix Wheel Tyre and Axle Works, Rotherham.

1868. Paget, Arthur, Machine Works, Loughborough.
1868. Parker, Frederick, Steam Plough and Locomotive Works, Leeds.
1868. Parker, Henry, 20 Mecklenburgh Square, Gray's Inn Road, London, W.C.
1865. Parkes, Alexander, Stephenson Metal Tube Works, Liverpool Street, Birmingham.
1866. Parton, Thomas, Rough Hay Iron Works, Darlaston, near Wednesbury.
1847. Peacock, Richard, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1867. Pearce, Robert Webb, Carriage Superintendent, East Indian Railway, Calcutta, India.

1848. Pearson, John, 7 Old Hall Street, Liverpool.

1866. Peel, George, Jun., Soho Iron Works, Pollard Street, Manchester.

1866. Peele, Arthur John, 90 Queen Street, London, E.C.

1848. Penn, John, The Cedars, Lee, London, S.E. (*Life Member.*)

1861. Perkins, Loftus, 6 Seaford Street, Regent Square, London, W.C.

1866. Perks, John Hartley, Shrubbery Iron Works, Wolverhampton.

1856. Perring, John Shae, 104 King Street, Manchester.

1863. Perry, Thomas J., Highfields Engine Works, Bilston.

1865. Perry, William, Messrs. Samuel Perry and Sons, Wednesbury.

1860. Peyton, Edward, Bordesley Works, Birmingham.

1867. Pidgeon, Daniel, Britannia Iron Works, Banbury.

1856. Piggott, George, Birmingham Heath Boiler Works, Birmingham.

1854. Pilkington, Richard, Jun., Wolsingham, near Darlington.

1859. Pitts, Joseph, Stanningley Iron Works, near Leeds.

1859. Platt, John, M.P., Hartford Iron Works, Oldham.

1867. Platt, Samuel Radcliffe, Hartford Iron Works, Oldham.

1862. Player, John, 3904 Walnut Street, Philadelphia, Pennsylvania, United States: (or care of William J. Player, Longford Court, Neath.)

1866. Plum, Thomas Edward Day, Atlas Works, Manchester.

1861. Plum, Thomas William, Old Park Iron Works, near Shiffnal.

1860. Ponsonby, Edward Vincent, Parker Place, Broomhill, Sheffield.

1866. Porter, Charles Talbot, 102 Broadway, New York, United States.

1861. Porter, Robert, 47 Paradise Street, Birmingham.

1864. Potts, Benjamin Langford Foster, 200 Camberwell Grove, London, S.E.

1851. Potts, John Thorpe, 200 Camberwell Grove, London, S.E.

1867. Powell, William, Harbour Works, Port Erin, Isle of Man.

1867. Pratchitt, John, Denton Iron Works, Carlisle.

1865. Pratchitt, William, Denton Iron Works, Carlisle.

1856. Preston, Francis, Ancoats Bridge Works, Ardwick, Manchester.

1866. Price, John, Chief Surveyor, Underwriters' Registry for Iron Vessels, 42 Villiers Street, Sunderland.

1866. Putnam, William, Darlington Forge, Darlington.

1868. Rafarel, Frederic William, Cwmbran Nut and Bolt Works, near Newport, Monmouthshire.

1862. Rake, Alfred Stansfield, Bank Buildings, Newcastle-on-Tyne.

1864. Ramage, Robert, Locomotive Superintendent, Midland Great Western Railway, Dublin.

1847. Ramsbottom, John, Locomotive Superintendent, London and North Western Railway, Crewe.

n, James, Abbot's Wood, Barrow-in-Furness, Lancashire.
e, Allen, Jun., Messrs. Worssam and Co., King's Road, Chelsea,
on, S.W.
e, Robert James, Orwell Works, Ipswich.
Daniel Rowlinson, Phœnix Safe Works, Liverpool.
George, London and North Western Railway, Locomotive
rtment, Crewe.
ll, John R., Glass House Fields, Ratcliff, London, E.
George Banks, 20 Lowndes Street, Lowndes Square, London, S.W.
s, Edward, Don Steel Works, Sheffield.
s, Frederic Cornell, 37 Great George Street, Westminster, S.W.
s, Edward Windsor, Ebbw Vale Iron Works, near Tredegar.
, Edwin, Tredegar Iron Works, Tredegar.
s, Job, Parkgate Iron Works, Rotherham.
s, Josiah, Abersychan Iron Works, Pontypool.
son, Edward, Lyttelton and Christchurch Railway, Christchurch,
Zealand.
son, John, Methley, near Leeds.
son, Thomas, Hartlepool Iron Works, Hartlepool.
son, William, Hartford Iron Works, Oldham.
Samuel, 18 Hopwood Avenue, Manchester.
amuel, Cock Hedge Mill, Warrington.
n, Henry, Great Western Railway, Shrewsbury.
obert, Perseverance Iron Works, Lincoln.
, John, Messrs. Sharp Stewart and Co., Atlas Works, Manchester.
, John, Railway Works, Rochdale.
Thomas, Mining Engineer, Lumley Colliery, Fence Houses.
William, Resident Engineer, Port Wakefield and Hoyles Plains
ay, Port Wakefield, near Adelaide, South Australia.
, Joseph P., 4 Harbour Hill, Queenstown.
enry Fullwood, Albert Iron Works, Moxley, near Wednesbury.
omas, Bradley Iron Works, near Bilston.
omas, Machine Works, 37 Victoria Street, Manchester.
, Joseph De, Messrs. Rosthorn Brothers, Vienna.
Frederick, Great Northern Railway, Locomotive Department,
n.
e, William, New Bridge Foundry, Adelphi Street, Salford,
hester.
Thomas William, 6A Victoria Street, Westminster, S.W.
Member.)
John Scott, 5 Westminster Chambers, Victoria Street,
minster, S.W.
Joseph, Sheaf Iron Works, Lincoln.

1866. Sacré, Alfred, Yorkshire Engine Co., Meadow Hall Works, near Sheffield.

1859. Sacré, Charles, Locomotive Superintendent, Manchester Sheffield and Lincolnshire Railway, Gorton, near Manchester.

1868. Sacré, Edward Antoine, 26 Parliament Street, Westminster, S.W.

1867. Sadoine, Eugène, Société Cockerill, Seraing, Belgium.

1864. Said, Colonel M., Bey, Engineer, Turkish Service, Constantinople: (or care of J. C. Frank Lee, 22 Great George Street, Westminster, S.W.)

1859. Salt, George, Saltaire, near Bradford, Yorkshire.

1864. Samuda, Joseph D'Aguilar, M.P., Iron Ship Building Yard, Isle of Dogs, Poplar, London, E.

1848. Samuel, James, 26 Great George Street, Westminster, S.W.

1857. Samuelson, Alexander, 27 Cornhill, London, E.C.

1865. Samuelson, Bernhard, M.P., Britannia Iron Works, Banbury.

1857. Samuelson, Martin, Engine Works, Neptune Street, Hull.

1865. Sandberg, Christer Peter, Engineer, Swedish Government Railway Service, Stockholm, Sweden: (or care of Messrs. Tottie and Sons, 2 Alderman's Walk, Bishopsgate Street, London, E.C.)

1861. Sanderson, George Grant, Tudhoe Iron Works, near Ferryhill.

1864. Sanderson, John, Flosh View, Wigton.

1860. Schneider, Henry William, Ulverstone Hæmatite Iron Works, Barrow-in-Furness, Lancashire.

1866. Scholtze, Aleksander, Messrs. Scholtze Brothers, Engineers and Boiler Makers, Warsaw, Poland.

1865. Scott, Edward, 10 Tib Lane, Cross Street, Manchester.

1868. Scott, George Lamb, 29 Greenhill Street, Greenheys, Manchester.

1861. Scott, Walter Henry, Locomotive and Carriage Superintendent, Mauritius Railways, Port Louis, Mauritius: (or care of Joseph Reid, 3 Alexandra Terrace, Stanstead Road, Forest Hill, London, S.E.)

1868. Scriven, Charles, Leeds Old Foundry, Marsh Lane, Leeds.

1864. Seddon, John, Wallgate, Wigan.

1857. Selby, George Thomas, Smethwick Tube Works, Birmingham.

1867. Selby, Millin, Teakova Cotton Mill, near Ivanova, Vladimir, Russia: (or care of Millin Selby, Sen., Atherton Hall, Leigh, near Manchester.)

1865. Sellers, William, Pennsylvania Avenue, Philadelphia, Pennsylvania, United States.

1850. Shanks, Andrew, 6 Robert Street, Adelphi, London, W.C.

1863. Sharp, Henry, Bolton Iron and Steel Works, Bolton.

1867. Sharpe, Charles James, 17B Great George Street, Westminster, S.W.

1862. Sharpe, William John, 17B Great George Street, Westminster, S.W.

1864. Shaw, Duncan, Mining Engineer, Cordova, Spain.

1856. Shelley, Charles Percy Bysshe, 113 Victoria Street, Westminster, S.W.

1861. Shepherd, John, Union Foundry, Hunslet Road, Leeds.

Shuttleworth, Joseph, Stamp End Iron Works, Lincoln.

Siemens, Charles William, 3 Great George Street, Westminster, S.W.

Silvester, John, Messrs. George Salter and Co., Spring Balance Works, Westbromwich.

Sinclair, Robert, Great Eastern Railway, Stratford, London, E.

Sinclair, Robert Cooper, Hartshill, near Atherstone.

Slater, Isaac, Gloucester Wagon Works, Gloucester.

Slaughter, Edward, Avonside Engine Works, Bristol.

Smethurst, Joseph, Guide Bridge Iron Works, Audenshaw, near Manchester.

Smith, Edward Fisher, Coneygre Iron Works, Dudley Port, Dudley.

Smith, Fereday, Bridgewater Offices, Manchester.

Smith, Henry, Brierley Hill Iron Works, Brierley Hill.

Smith, Isaac, 36 Lancaster Street, Birmingham.

Smith, John, Brass Foundry, Traffic Street, Derby.

Smith, Josiah Timmis, Ulverstone Hæmatite Iron Works, Barrow-in-Furness, Lancashire.

Smith, Matthew, Caledonia Wire Mills, Halifax.

Smith, William, 19 Salisbury Street, Adelphi, London, W.C.

Smith, William, Eglinton Engine Works, Glasgow.

Smith, William Ford, Gresley Iron Works, Ordsal Lane, Salford, Manchester.

Snowdon, Thomas, 147 High Street, Stockton-on-Tees.

Sokoloff, Colonel Alexander, Engineer, Russian Imperial Service, Steam Marine Department, Cronstadt, Russia : (or care of Messrs. W. Collier and Co., 2 Greengate, Salford, Manchester.)

Somerville, Wallace Cochrane, London Works, Birmingham.

Sörensen, Bergerius, Engineer-in-Chief, Royal Norwegian Navy Department, Horten Dockyard, Norway: (or care of Messrs. Tottie and Sons, 2 Alderman's Walk, Bishopsgate Street, London, E.C.)

Sparrow, Arthur, Lane End Iron Works, Longton, near Stoke-upon-Trent.

Sparrow, William Mander, Osier Bed Iron Works, Wolverhampton.

Spencer, Eli, Hartford Iron Works, Oldham.

Spencer, John Frederick, Oakhill, near Bath.

Spencer, John W., Newburn Steel Works, Newcastle-on-Tyne.

Spencer, Thomas, Clough Hall Iron Works, Kidsgrove, near Stoke-upon-Trent.

Spencer, Thomas, Newburn Steel Works, Newcastle-on-Tyne.

Spittle, Thomas, Cambrian Iron Foundry, Newport, Monmouthshire.

Stableford, William, Oldbury Carriage Works, near Birmingham.

Stenson, William Towndrow, Whitwick Colliery, Coalville, near Leicester.

Stephens, John Classon, Blackhall Place Iron Works, Dublin.

1868. Stephenson, George Robert, 24 Great George Street, Westminster, S.W.
1866. Stevenson, John, Acklam Iron Works, Middlesbrough.
1867. Stevenson, Robert, Mining Engineer, Clay Cross, near Chesterfield.
1859. Stewart, Charles P., Messrs. Sharp Stewart and Co., Atlas Works, Manchester.
1851. Stewart, John, Blackwall Iron Works, Russell Street, Blackwall, London, E.
1867. Stirling, Patrick, Locomotive Superintendent, Great Northern Railway, Doncaster.
1864. Stokes, James Folliott, 21 Parliament Street, Westminster, S.W.
1863. Storey, John Henry, Knott Mill Brass and Copper Works, Little Peter Street, Manchester.
1862. Strong, Joseph F., Resident Engineer, East Indian Railway, Cawnpore, India.
1865. Stroudley, William, Locomotive Superintendent, Highland Railway, Inverness.
1861. Sumner, William, 2 Brazenose Street, Manchester.
1860. Swindell, James Evers, Parkhead Iron Works, Dudley.
1864. Swindell, James Swindell Evers, Cradley Iron Works, near Brierley Hill.
1867. Swingler, Henry, Victoria Foundry, Litchurch, near Derby.
1859. Swingler, Thomas, Victoria Foundry, Litchurch, near Derby.

1861. Tangye, James, Cornwall Works, Clement Street, Birmingham.
1859. Tannett, Thomas, Victoria Foundry, Leeds.
1861. Taylor, George, Clarence Iron Works, Leeds.
1858. Taylor, James, Britannia Engine Works, Cleveland Street, Birkenhead.
1862. Taylor, John, Mining Engineer, 6 Queen Street Place, Upper Thames Street, London, E.C.
1867. Taylor, Joseph, Derwent Foundry, 99 Constitution Hill, Birmingham.
1862. Taylor, Richard, Mining Engineer, 6 Queen Street Place, Upper Thames Street, London, E.C.
1868. Taylor, Samuel, Clarence Iron Works, Leeds.
1864. Tennant, Charles, The Glen, Innerleithen, near Edinburgh. (*Life Member.*)
1867. Thomas, Joseph Lee, 7 Holland Terrace, Kensington, London, W.
1864. Thomas, Thomas, Llynvi Vale Iron Works, near Bridgend.
1857. Thompson, Robert, Haigh Foundry, near Wigan.
1862. Thompson, William, Spring Gardens Engine Works, Newcastle-on-Tyne.
1852. Thomson, George, Crookhay Iron Works, Westbromwich.
1868. Thomson, John, Engine Works, 36 Finnieston Street, Glasgow.
1865. Thorn, Alexander, Steam Saw Mills, Chelsea, London, S.W.
1868. Thornewill, Robert, Burton Iron Works, Burton-on-Trent.

1861. Thwaites, Robinson, Vulcan Iron Works, Thornton Road, Bradford, Yorkshire.

1865. Tickle, John, Providence Engine Works, Westbromwich.

1862. Tijou, William, 27 Great George Street, Westminster, S.W.

1862. Tolmé, Julian Horn, 1 Victoria Street, Westminster, S.W.

1857. Tomlinson, Joseph, Jun., Locomotive Superintendent, Taff Vale Railway, Cardiff.

1867. Tonks, Edmund, Brass Works, Moseley Street, Birmingham.

1865. Toomey, Edward, Royal Phœnix Iron Works, Dublin.

1856. Tosh, George, Locomotive Superintendent, Maryport and Carlisle Railway, Maryport.

1860. Townsend, Thomas C., 16 Talbot Chambers, Shrewsbury.

1863. Townsend, William, West Orchard, Coventry.

1865. Trow, John James, Timber Works, Bilston Road, Wednesbury.

1862. Troward, Charles, 8 Sussex Terrace, Camden Town, London, N.W.

1859. Turner, Edwin, Ashfield, Bradford, Yorkshire.

1866. Turner, Frederick, St. Peter's Iron Works, Ipswich.

1867. Turner, Henry, Thames Ship Building Works, Orchard Yard, Blackwall, London, E.

1867. Tweddell, Ralph Hart, 44 West Sunniside, Sunderland.

1856. Tyler, Captain Henry Wheetley, R.E., Railway Department, Board of Trade, Whitehall, London, S.W.

1862. Upward, Alfred, Engineer, Chartered Gas Works, 146 Goswell Street, London, E.C.

1865. Usher, George Moon, Beverley Iron Works, Beverley.

1868. Vallance, Frederick Bevoley, Alicel Engine Works, Bridge Street, Greenwich, S.E.

1862. Vavasseur, Josiah, 28 Gravel Lane, Southwark, London, S.E.

1856. Vernon, John, Regent Road, Sandon Dock, Liverpool.

1865. Vickers, Albert, Don Steel Works, Sheffield.

1861. Vickers, Thomas Edward, Don Steel Works, Sheffield.

1856. Waddington, John, 35 King William Street, London Bridge, London, E.C.

1856. Waddington, Thomas, Heaton Lodge, Wortley, near Leeds.

1865. Wainwright, William, Great Western Railway, Locomotive Department, Worcester.

1863. Wakefield, John, Locomotive Superintendent, Dublin Wicklow and Wexford Railway, Dublin.

1867. Walker, Benjamin, Goodman Street Works, Hunslet, Leeds.

1864. Walker, Bernard Peard, Junction Cut Nail Works, Wolverhampton.

1867. Walker, Charles Clement, Midland Iron Works, Donnington, near Newport, Shropshire.

1847. Walker, Thomas, Patent Shaft Works, Wednesbury.

1863. Walker, William Hugill, Wicker Iron Works, Sheffield.

1863. Wallace, William, Superintending Engineer, Montreal Ocean Steam Ship Works, Liverpool.

1865. Waller, George Arthur, Messrs. Guinness, James' Gate, Dublin.

1868. Wallis, Herbert, Midland Railway, Locomotive Department, Bradford, Yorkshire.

1865. Walpole, Thomas, Port of Dublin Ship Yard, Dublin.

1864. Warden, Walter Evers, Phœnix Bolt and Nut Works, Glover Street, Birmingham.

1856. Wardle, Charles Wetherell, Boyne Engine Works, Hunslet, Leeds.

1852. Warham, John R., Burton Iron Works, Burton-on-Trent.

1867. Watkin, William John Laverick, Mining Engineer, Pemberton Colliery, near Wigan.

1862. Watkins, Richard, Canal Iron Works, Poplar, London, E.

1866. Watson, Robert, Engineer, Black Boy Collieries, Bishop Auckland.

1862. Webb, Francis William, Bolton Iron and Steel Works, Bolton.

1862. Webb, Henry Arthur, Bretwell Hall Iron Works, near Stourbridge.

1860. Weild, William, Tipping Street, Ardwick, Manchester.

1862. Wells, Charles, Moxley Iron Works, near Bilston.

1862. Westmacott, Percy G. B., Elswick Engine Works, Newcastle-on-Tyne.

1867. Weston, Thomas Aldridge, care of William T. Watts, 78 Parade, Birmingham.

1867. Wheatley, Thomas, Locomotive Superintendent, North British Railway, Edinburgh.

1856. Wheeldon, Frederick R., Highfields Engine Works, Bilston.

1864. White, Isaiah, Messrs. Portilla and White, Engineers and Iron Ship Builders, Seville, Spain: (or care of Isaac White, Pontardulais, Llanelly.)

1868. Whitehead, Peter Ormerod, Ilex Cotton Mill, Rawtenstall, near Manchester.

1862. Whitehead, William, Don Steel Works, Sheffield.

1859. Whitham, James, Perseverance Iron Works, Kirkstall Road, Leeds.

1863. Whitley, Joseph, New British Iron Works, Corngreaves, near Birmingham.

1866. Whitwell, Thomas, Thornaby Iron Works, Stockton-on-Tees.

1847. Whitworth, Joseph, Chorlton Street, Manchester.

1859. Wickham, Lamplugh Wickham, Low Moor Iron Works, near Bradford, Yorkshire.

1863. Wicksteed, Thomas, 8 Torquay Terrace, Headingley, near Leeds. (*Life Member.*)

1868. Wigham, John Richardson, Stafford Works, Stafford Street, Dublin.

Vigram, Reginald, Steam Plough and Locomotive Works, Leeds.
Vilkes, Gilbert, Tube Works, Bordesley Mills, Birmingham.
Vilkes, John, Tube Works, Bordesley Mills, Birmingham.
Vilkieson, Lt.-Colonel Charles Vaughan, R.E., care of Messrs. Richardson and Co., 13 Pall Mall, London, S.W.
Villiams, Edward, Messrs. Bolckow and Vaughan's Iron Works, Middlesbrough.
Villiams, Richard, Patent Shaft Works, Wednesbury.
Villiams, Richard Price, 37 Great George Street, Westminster, S.W.
Vilson, Edward, 9 Dean's Yard, Westminster, S.W.
Vilson, George, Cyclops Steel and Iron Works, Sheffield.
Vilson, Henry, Brass Works, Stockton-on-Tees.
Vilson, James Edwards, Engineer, Indian Branch Railways, Cawnpore, India.
Vilson, John Charles, East India House, 5 Lime Street, London, E.C.
Vilson, Joseph W., 19 Craven Street, Strand, London, W.C.
Vilson, Robert, Bridgewater Foundry, Patricroft, near Manchester.
Vilson, William, 4 Victoria Street, Westminster, S.W.
Vinby, Clifford Etches, Atlas Iron Works, Cardiff.
Vinby, Frederick Charles, Atlas Iron Works, Cardiff.
Vinby, William Edward, Old Park Iron Works, Wednesbury.
Vinter, Thomas Bradbury, 28 Moorgate Street, London, E.C.
Vise, Francis, Chandos Chambers, Buckingham Street, Adelphi, London, W.C.
Vood, Lindsay, Mining Engineer, Hetton Colliery, Hetton, near Fence Houses.
Voodall, Solomon, Windmill End Boiler Works, near Dudley.
Voodhouse, Henry, London and North Western Railway, Stafford.
Voodhouse, John Thomas, Mining Engineer, Midland Road, Derby.
Voods, Hamilton, Liver Foundry, Ordsal Lane, Salford, Manchester.
Vorthington, Samuel Barton, Engineer, London and North Western Railway, Manchester.
Vray, William, Ship Building Yard, Burton Stather, near Brigg.
Vren, Henry, London Road Iron Works, Manchester.
Vright, John Turner, Universe Rope Works, Garrison Street, Birmingham.
Vright, Joseph, Metropolitan Carriage and Wagon Company, Saltley Works, Birmingham.
Vright, Joseph, Neptune Forge, Tipton Green, Dudley.
Vright, Owen, Broadwell Forge, Oldbury, near Birmingham.
Vright, Peter, Railway Wheel Vice and Anchor Works, Dudley.
Vyllie, Andrew, Vauxhall Foundry, Liverpool.
Vymer, Francis W., Surveyor of Steam Vessels, Board of Trade, Greenock.

1861. Yule, William, 102 New Canal, St. Petersburg.

HONORARY LIFE MEMBERS.

1865. Downing, Samuel, LL.D., Museum Building, Trinity College, Dublin.
1847. Fairbairn, William, LL.D., The Polygon, Ardwick, Manchester.
1867. Morin, General Arthur, Director, Conservatoire Impérial des Arts et Métiers, Paris.
1867. Tresca, Henri, Engineer Sub-Director, Conservatoire Impérial des Arts et Métiers, Paris.

ASSOCIATES.

1865. Barker, Frederick, Leeds Iron Works, Leeds.
1868. Beale, Montague, 1 Great Winchester Street Buildings, London, E.C.
1867. Blinkhorn, William, London and Manchester Plate Glass Works, Sutton, St. Helen's.
1866. Chadwick, William, Monkbridge Iron Works, Leeds.
1848. Crosby, Samuel, Tenby House, Victoria Road, Aston, Birmingham.
1866. Crossley, John, British Plate Glass Works, Ravenhead, near St. Helen's.
1867. Dewhurst, John Bonny, Bellevue Cotton Mills, Skipton.
1863. Fisher, John, Priory Street, Dudley.
1863. Forster, George Emmerson, Collingwood Chambers, Newcastle-on-Tyne.
1865. Gössell, Otto, 22 Moorgate Street, London, E.C.
1865. Hall, John, 56 King Street, Manchester.
1864. Hornblower, Joseph Wells, 14 Waterloo Street, Birmingham.
1858. Lawton, Benjamin C., 44 Westgate Street, Newcastle-on-Tyne.
1859. Leather, John Towlerton, Leventhorpe Hall, near Leeds. (*Life Associate.*)
1865. Longsdon, Alfred, 11 New Broad Street, London, E.C.
1860. Manby, Cordy, Tower Street, Dudley.
1868. Matthews, Thomas Bright, Globe Steel Works, Sheffield.
1867. Neave, William Alexander, Poste Restante, Lausanne, Switzerland.
1863. Nichols, William, Midland Copper Works, Guild Street, Burton-on-Trent.
1865. Parry, David, Leeds Iron Works, Leeds.
1864. Parsons, Charles T., Ann Street, Birmingham.
1856. Pettifor, Joseph, Midland Railway, Derby.
1861. Ratcliff, Charles, Wyddrington, Edgbaston, Birmingham.
1863. Rigg, Arthur, The College, Chester.
1867. Roe, Thomas, Jun., Siddals Road, Derby.
1866. Scott, John Peers, 10 Tib Lane, Cross Street, Manchester.
1859. Sherriff, Alexander Clunes, M.P., Great Western Railway, Worcester.
1863. Storey, Thomas R., Bond Court House, Walbrook, London, E.C.

ant, John, St. Rollox Chemical Works, Glasgow. (*Life Associate.*)
nton, Falkland Samuel, Bradford Street, Birmingham.
len, Thomas, Lionel Street, Birmingham.
len, William Marston, Edgbaston Street, Birmingham.
rhouse, Thomas, Claremont Place, Sheffield.
s, William Thomas, 78 Parade, Birmingham.
e, Richard Lewis, Great Western Railway, Swindon.
ley, Joseph, Bowman Lane, Leeds.
ley, John, Marehay Colliery, Ripley, near Derby.

GRADUATES.

r, James, Atlas Works, Manchester.
r, Thomas Snowden, Kirkstall Forge, Leeds.
Nevil John, Great Western Railway, Locomotive Department, vindon.
nes, James Charles, Midland Railway, Locomotive Department, Derby.
rd, William Henry, 77 Lower Loveday Street, Birmingham.
l, Sidney, Jun., Eagle Foundry, Leamington.
on, George, Spring Hill Tube and Metal Works, Eyre Street, rmingham.
Henry Walker, 241 Dewsbury Road, Leeds.
nd, George, care of John Holland, Contractor, Northwich.
phrys, Robert Harry, Deptford Pier, London, S.E.
, George Edward, Horseley Iron Works, Tipton.
in, Frank, Sheaf Works, Sheffield.
ew, Horace, Mining Engineer, Wigan.
nell, John, Swaithe Colliery, Barnsley.
, William, Jun., Hetton Colliery, Hetton, near Fence Houses.
on, John Edward, Spring Colliery, Ince Hall, near Wigan.
d, Frederick, Messrs. Kenrick's Works, Spon Lane, Westbromwich.
len, Howard William, Horseley Iron Works, Tipton.
steed, Joseph Hartley, Well House Foundry, Leeds.
ht, John Roper, Landore Steel Works, Swansea.

PROCEEDINGS.

30 JANUARY, 1868.

he TWENTY-FIRST ANNIVERSARY MEETING of the Members was in the Lecture Theatre of the Midland Institute, Birmingham, hursday, 30th January, 1868; SAMPSON LLOYD, Esq., Vice- dent, in the Chair.

he Minutes of the last General Meeting were read and confirmed.

he Secretary then read the following

ANNUAL REPORT OF THE COUNCIL.

1868.

he Council have great pleasure, on the occasion of the Twenty- Anniversary of the Institution, in congratulating the Members the very satisfactory position and the continued progress of the ution.

he Financial statement of the affairs of the Institution for the ending 31st December 1867 shows a balance in the Treasurer's s of £4717 13*s.* 11*d.* after the payment of the accounts due to date. The Finance Committee have examined and checked the pts and payments of the Institution for the last year 1867, and t that the following Balance Sheet rendered by the Treasurer is ct. (*See Balance Sheet appended.*)

he Council report with great satisfaction the large increase in umber of Members that has taken place during the year; the number of Members of all classes for the year being 791, of n 4 are Honorary Life Members, 39 are Associates, and 17 are uates, being an effective increase of 63 during the year.

The following deceases of Members of the Institution have occurred during the past year 1867 :—

William Carpmael, Sen.,	London.
Robert Hawthorn,	Newcastle-on-Tyne.
Edward Humphrys,	London.
William Jenkins,	Manchester.
Frederick Levick,	Blaina.
William Ryder,	Bolton.
Frank Shaw,	Burton-on-Trent.
Henry Wickham Wickham,	Bradford.

Of the above Members Mr. Robert Hawthorn was a Vice-President of the Institution for several years past, and Mr. Edward Humphrys a member of the Council, both of them having been Members of the Institution from the commencement.

The Council have the pleasure of acknowledging the following Donations to the Library of the Institution during the past year; and also of expressing their thanks to the Donors for the valuable and acceptable additions they have presented. The Council wish to urge on the attention of the Members the important advantage of obtaining a good collection of Engineering Books, Drawings, and Models or Specimens of interest in the Institution, for the purpose of reference by the Members personally or by correspondence; and they trust this desirable object will be promoted by the Members generally, so that by their united aid it may be efficiently accomplished. Members are requested to present copies of their Works to the Library of the Institution.

LIST OF DONATIONS TO THE LIBRARY.

On the State of Public Works in Spain; from Don José de Echeverria.
On the Construction of Iron Ships, by John Price; from the author.
Life and Times of the Marquis of Worcester, by Henry Dircks; from the author.
History of Perpetual Motion, do. do.
Memoir of Samuel Hartlib, do. do.
Optical Illusions, do. do.
Electro-Metallurgy, do. do.
On Applied Mechanics, by W. J. Macquorn Rankine; from the author.
On Apparent Negative Slip in Screw Steamers, do. do.
Report of the Smithsonian Institution for 1865; from the Institution.

Annual Report of the Secretary of War of the United States; from the Secretary.

Report of the Public Schools of Pennsylvania; from Mr. Edward Shippen.

Memoir of Parkin Jeffcock, by Rev. J. T. Jeffcock; from the author.

Stannah's Tables for Engineers; from the author.

Photographs of the Blackfriars Bridge Works; from Mr. Frederick W. Bryant.

Proceedings of the Institution of Civil Engineers; from the Institution.

Proceedings of the French Institution of Civil Engineers; from the Institution.

Bulletin of the French Society for the Encouragement of National Industry; from the Society.

Transactions of the Institution of Civil Engineers of Ireland; from the Institution.

Report of the British Association for the Advancement of Science; from the Association.

Proceedings of the South Wales Institute of Engineers; from the Institute.

Transactions of the Institution of Engineers in Scotland; from the Institution.

Transactions of the Society of Engineers; from the Society.

Proceedings of the Royal Institution of Great Britain; from the Institution.

Journal of the Hannover Architect and Engineers' Society; from the Society.

Journal of the Norwegian Polytechnic Society; from the Society.

Journal of the Royal United Service Institution; from the Institution.

Transactions of the Royal Scottish Society of Arts; from the Society.

Proceedings of the Philosophical Society of Glasgow; from the Society.

Report of the Royal Cornwall Polytechnic Society; from the Society.

Reports of the Manchester Association for the Prevention of Steam Boiler Explosions; from Mr. Lavington E. Fletcher.

Report of the Manchester Boiler Insurance Company; from Mr. Robert B. Longridge.

Reports of the Midland Steam Boiler Association; from Mr. Edward B. Marten.

Report of the British Association of Gas Managers; from the Association.

United States Patent Office Reports; from the Commissioner.

Journal of the Board of Arts and Manufactures for Upper Canada; from the Board.

Journal of the Society of Arts; from the Society.

The Engineer; from the Editor.

Engineering; from the Editor.

The Mechanics' Magazine; from the Editor.

The Civil Engineer and Architect's Journal; from the Editor.

The Artizan Journal; from the Editor.

The Practical Mechanic's Journal; from the Editor.

The Mining Journal; from the Editor.

The Railway Record; from the Editor.

The Steam Shipping Journal; from the Editor.

The Council have great satisfaction in referring to the number and character of the Papers that have been brought before the meetings during the past year, and the practical value and interest of the communications and the discussions that took place upon them, which form a valuable addition to the Proceedings of the Institution. The Council request the special attention of the Members to the importance of their aid and co-operation in carrying out the objects of the Institution and maintaining its advanced position, by contributing papers on Engineering subjects that have come under their observation, and communicating the particulars and results of executed works and practical experiments that may be serviceable and interesting to the Members; and they invite communications upon the subjects in the list appended and other subjects advantageous to the Institution.

The following Papers have been read at the Meetings during the last year:—

Description of the Paying-Out and Picking-Up Machinery employed in laying the Atlantic Telegraph Cable; by Mr. George Elliot, of London.

On the Composition and Durability of Locomotive Boiler Tubes in reference to Coal-Burning; by Mr. George A. Everitt, of Birmingham.

On the Ventilation of Public Buildings; by General Morin.

On Floating Docks, and other arrangements for affording access to Ships for external repairs; by Mr. Frederick J. Bramwell, of London.

On the "Flow of Solids," with the practical application in Forgings &c.; by M. Tresca.

On Mechanical Puddling; by Mr. William Menelaus, of Dowlais.

On the Machinery for Boring Artesian Wells; by M. Dru, of Paris.

On the Steam Dredgers employed in the excavation of the Isthmus of Suez Canal; by M. Borel, of Paris.

Description of a 30-Ton Horizontal Duplex Hammer; by Mr. John Ramsbottom, of Crewe.

Description of the Crossness Pumping Engines for the Metropolitan Main Drainage Works; by Mr. Gilbert Hamilton, of Messrs. James Watt & Co.

Description of an improved Steam Pile Driver with endless chain; by Mr. Peter B. Eassie, of Gloucester.

Description of the Steam Steering Engine in the "Great Eastern" steamship; by Mr. J. McFarlane Gray, of Liverpool.

The Council have particular pleasure in referring to the great success and the very gratifying results of the Annual Meeting of the Institution that was held in Paris last summer, during the time of the International Exhibition, which was supported by an unusually large attendance of the Members. The Council desire to express their special thanks to the authorities of the Conservatoire Impérial des Arts et Métiers, and to the Honorary Local Secretary, Mr. Henry Chapman, for the very excellent arrangements made for the Meeting and the very kind and cordial reception given to the Members on the occasion; and also their thanks to the proprietors of the works which were so liberally thrown open to the inspection of the Members, for the valuable opportunity afforded to the Members for seeing their works; and they refer specially to the opportunity of visiting the Observatory, upon the obliging invitation of the astronomer royal, M. Leverrier, and also the works of the Artesian Wells in progress of sinking in Paris. The Council look forward with confidence to the important advantages arising from the continuance of these Annual Meetings in different localities, from the facilities afforded by them for the personal communication of the Members in different districts, and from the opportunities of visiting the important Engineering Works that are so liberally thrown open to their inspection on those occasions.

The Council have the pleasure of reporting that an Honorary Life Membership in the Institution has been presented to General Morin, Director of the Conservatoire Impérial des Arts et Métiers, and also to M. Tresca, Engineer Sub-Director of the Conservatoire, as an expression of acknowledgment of the great obligation to them for the very important and valuable aid rendered by them on the occasion of the Paris Meeting of the Institution, as well as in recognition of their valuable contributions to Engineering Science.

The President, Vice-Presidents, and five of the Members of the Council in rotation, go out of office this day, according to the rules of the Institution; and the ballot will be taken at the present Meeting for the election of the Officers and Council for the ensuing year.

SUBJECTS FOR PAPERS.

STEAM ENGINE BOILERS, particulars of construction—form and extent of heating surface—relative value of radiant surface and flue surface in effect and economy—cost—consumption of fuel—evaporation of water—pressure of steam—density and heat of steam—superheated steam, simple or mixed with common steam—pressure gauges—safety valves—water gauges—explosion of boilers, and means of prevention—effects of heat on the metal of boilers, low-pressure and high-pressure—steel boilers—cast-iron boilers—welded boilers—incrustation of boilers, and means of prevention—corrosion of boilers, and means of prevention—effects of surface condensers on the metal of boilers—evaporative power and economy of different kinds of fuel, coal, wood, charcoal, peat, patent coal, and coke—moveable grates, and smoke-consuming apparatus, facts to show the best plan, and results of working—plans for heating feed water—mode of feeding—use of injector—circulation of water.

STEAM ENGINES—expansive force of steam, and best means of using it—power obtained by various plans—comparison of double and single cylinder engines—combined engines—compound cylinder engines—comparative advantages of direct-acting and beam engines—engines for manufacturing purposes—horizontal and vertical—condensing and non-condensing—injection and surface condensers—air pumps—governors—valves—bearings, &c.—improved expansion gear—indicator diagrams from engines, with details of useful effect, consumption of fuel, &c.—contributions of indicator diagrams for reference in the Institution.

PUMPING ENGINES, particulars of various constructions—Cornish engines, beam engines with crank and flywheel, direct-acting engines with and without flywheel—size of steam cylinder and degree of expansion—number and size of pumps, and strokes per minute—speed of piston—pressure upon pump—effective horse power and duty—comparison of double-acting and single-acting pumping engines—construction of pumps—plunger pumps—bucket pumps—particular details of different valves—india-rubber valves, durability and results of working—diagrams of lift of valves—application of pumps—fen-draining engines—comparative advantages of scoop wheels and centrifugal pumps, lifting trough, &c.—sewage pumping engines—details of pit work of pumping engines in mines.

BLAST ENGINES, best kind of engine—size of steam cylinder, strokes per minute, and horse power—details of boilers—size of blowing cylinder, and strokes per minute—pressure of blast, and means of regulation—construction of valves—improvements in blast cylinders—rotary blowing machines—indicator diagrams from air main and steam cylinder.

MARINE ENGINES, power of engines in proportion to tonnage—different constructions of engines, double cylinder engines, trunk engines—three-cylinder engines—use of steam jackets—dynamical effect compared with indicator diagrams—comparative economy and durability of different boilers, tubular boilers, flat-flue boilers, &c.—brine pumps, and means of preventing deposit—salinometers—weight of machinery and boilers—kind of paddle wheels—speed obtained in British war steamers, in British merchant steamers, and in Foreign ditto, with particulars of the construction of engines with paddle wheels, &c.—screw propellers, particulars of different kinds, improvements in form and position, number of arms, material, means for unshipping, bearings, horse power applied, speed obtained, section of vessel—reaction propellers—governors and storm governors.

ROTARY ENGINES, particulars of construction and practical application—details of results of working.

LOCOMOTIVE ENGINES, particulars of construction, details of experiments, and results of working—consumption of fuel—relative value and evaporative duty of coke and coal—consumption of smoke—use of wood and construction of spark arresters—heating surface, length and diameter of tubes—material of tubes—experiments on size of tubes and blast pipe—construction of pistons, valve gear, expansion gear, &c.—indicator diagrams—expenses of working and repairs—means of supplying water to tenders—locomotives for steep gradients and sharp curves—distribution of weight on wheels.

AGRICULTURAL ENGINES, details of construction and results of working—duty obtained—application of machinery and steam power to agricultural purposes—barn machinery—field implements—traction engines, particulars of performance and cost of work done.

CALORIC ENGINES—engines worked by gas, or explosive compounds—electro-magnetic engines—particulars and results.

HYDRAULIC ENGINES, particulars of application and working—pressure of water—construction and arrangement of valves, relief valves—construction of joints—hydraulic rams.

WATER WHEELS, particulars of construction and dimensions—form and depth of buckets—head of water, velocity, percentage of power obtained—turbines, construction and practical application, power obtained, comparative effect and economy—transmission of power to distant points.

WIND MILLS, particulars of construction—number of sails, surface and form of sails—velocity, and power obtained—average number of days' work per annum.

CORN MILLS, particulars of improvements—power employed—application of steam power—results of working with an air blast and ring stones—crushing by rolls before grinding—advantages of regularity of motion.

Sugar Mills, particulars of construction and working—results of application of the hydraulic press in place of rolls—application of steam and water for extracting the last portion of saccharine matter—construction and working of evaporating pans.

Oil Mills, facts relating to construction and working, by stampers, by screw presses, and by hydraulic presses—particulars of crushing rollers and edge stones.

Cotton Mills, information respecting the construction and arrangement of the machinery—power employed, and application of power—cotton presses, mode of construction and working, power employed—improvements in spinning, carding, and winding machinery, &c.

Calico-Printing and Bleaching Machinery, particulars of improvements.

Wool Machinery, carding, combing, roving, spinning, &c.

Flax Machinery, manufacture of flax, china grass, and other fibrous materials, both in the natural length of staple and when cut.

Weaving Machinery, for manufacture of different materials—improvements in looms, &c.

Rope-Making Machinery—hemp and wire ropes, comparative strength, durability, and cost—steel wire ropes—transmission of power by ropes, percentage of loss, distance, wear of ropes, &c.

Saw Mills, particulars of construction—mode of driving—power employed—particulars of work done—best speeds for vertical and circular saws—form of saw teeth—saw mills for cutting ship timbers—veneer saws—endless band saws.

Wood-Working Machines, morticing, dovetailing, planing, rounding, and surfacing—copying machinery.

Glass Machinery—manufacture of plate and sheet glass—construction of heating furnaces, annealing kilns, &c.—grinding and polishing machinery.

Lathes, Planing, Boring, Drilling, Slotting, and Shaping Machines, &c., particulars of improvements—description of new self-acting tools—engineers' tools—files and file-cutting machinery.

Rolling Mills, improvements in machinery for making iron and steel—mode of applying power—use of steam hammers—piling of iron—plates—fancy sections—arrangement and speed of rolls—length of bar rolled—manufacture of rolled girders—rolling of armour plates—reversing rolls.

Steam Hammers, improvements in construction and application—friction hammers—air hammers.

Rivetting, Punching, and Shearing Machines, worked by steam or hydraulic pressure—direct-acting and lever machines—portable machines—comparative strength of drilled and punched plates—rivet-making machines.

Stamping and Coining Machinery, particulars of improvements, &c.

Locks, and lock-making machinery—iron safes.

Paper-Making and Paper-Cutting Machines, new materials and results.

Printing Machines, particulars of improvements, &c.—machines for printing from engraved surfaces—type composing and distributing machines.

Water Pumps, facts relating to the best construction, means of working, and application—velocity of piston—construction, lift, and area of valves.

Air Pumps, facts relating to the best construction, means of working, and application—velocity of piston—construction, lift, and area of valves.

Hydraulic Presses, facts relating to the best construction, means of working, and application—economical limit of pressure.

Rotary and Centrifugal Pumps, ditto ditto ditto.

Fire Engines, hand and steam, ditto ditto ditto.

Sluices and Sluice Cocks, worked by hand or hydraulic power, ditto.

Cranes—steam, hydraulic, and pneumatic cranes—travelling cranes.

Lifts for raising railway wagons—hoists for warehouses—safety apparatus.

Toothed Wheels, best construction and form of teeth—results of working—strength of iron and wood teeth—moulding by machinery.

Driving Belts and Straps, best make and material, leather, gutta-percha, vulcanised india-rubber, rope, wire, chain, &c.—comparative durability, and results of working—power communicated by certain sizes—frictional gearing, construction and driving power obtained—friction clutches—shafting and couplings.

Dynamometers, construction, application, and results of working.

Decimal Measurement—application of decimal system of measurement to mechanical engineering work—drawing and construction of machinery, manufactures, &c.—construction of measuring instruments, gauges, &c.

Strength of Materials, facts relating to experiments, and general details of the proof of girders, &c.—girders of cast and wrought iron, particulars of different constructions, and experiments on them—rolled girders—best forms and proportions of girders for different purposes—best mixture of metal—mixtures of wrought iron with cast.

Durability of Timber of various kinds—best plans for seasoning and preserving timber and cordage—results of various processes—comparative durability of timber in different situations—experiments on actual strength of timber.

Corrosion of Metals by salt and fresh water, and by the atmosphere, &c.—facts relating to corrosion, and best means of prevention—means of keeping ships' bottoms clean—galvanic action, nature and preventives.

Alloys of Metals, facts relating to different alloys.

Friction of Various Bodies, facts relating to friction under ordinary circumstances—facts on increase of friction by reduction of surface in contact—friction of iron, brass, copper, tin, wood, &c.—proportion of weight to rubbing surface—best forms of journals, and construction of axleboxes—

wood bearings—water axleboxes—lubrication, best materials, means of application, and results of practical trials—best plans for oil tests—friction breaks.

Iron Roofs, particulars of construction for different purposes—durability in various climates and situations—comparative cost, weight, and durability—roofs for slips of cast-iron, wrought-iron, timber, &c.—best construction, form, and materials—details of large roofs, and cost.

Fire-proof Buildings, particulars of construction—most efficient plan—results of trials.

Chimney Stacks of large size—particulars, form, mode of building, cheapest construction, &c.—force of draught, and temperature of current.

Bricks, manufacture, durability, and strength—hollow bricks, fire bricks, and fire clay—perforated bricks, cost of manufacture, and advantages—dry-clay bricks—machines for brick-making—burning of bricks.

Gas Works, best form, size, and material for retorts—construction of retort ovens—quantity and quality of gas from different coals—oil gas, cheapest mode of making—water gas, &c.—improvements in purifiers, condensers, and gasholders—wet and dry gas meters—self-regulating meters—pressure of gas, gas exhauster—gas pipes, strength and durability, and construction of joints—proportionate diameter and length of gas mains, and velocity of the passage of gas—experiments on ditto, and on the friction of gas in mains, and loss of pressure—lighting railway trains with gas.

Water Works, facts relating to water works—application of power, and economy of working—proportionate diameter and length of pipes—experiments on the discharge of water from pipes, and friction through pipes—strength and durability of pipes, and construction of joints—penetration of frost in different climates—relative advantages of stand pipes and air vessels—sluices and self-acting valves—machinery for working sluices—water meters, construction and working.

Well Sinking and Artesian Wells, facts relating to—boring tools, construction and mode of using.

Tunnelling Machines, particulars of construction, and results of working.

Cofferdams and Piling, facts relating to construction—cast-iron sheet piling.

Piers, fixed and floating, and pontoons, ditto ditto.

Pile Driving Apparatus, particulars of improvements—use of steam power—particulars of working—weight of ram and height of fall, total number of blows required—vacuum piles—compressed air system—screw piles—pile shoes.

Dredging Machines, particulars of improvements—application of dredging machines—power required and work done.

Diving Bells and Diving Dresses, facts relating to the best construction.

Lighthouses, cast-iron and wrought-iron, ditto ditto.

SHIPS, iron and wood—details of construction—lines, tonnage, cost per ton—water ballast—steel masts and yards, and wire-rope rigging—comparative strength and advantage of iron and wood ships—arrangements for docking and repairing ships—steering gear—application of steam power to steering.

GUNS, cast-iron, wrought-iron, and steel—manufacture and proof—rifling—manufacture of shot and shells.

SMALL ARMS, machinery for manufacture of rifles and cartridges, &c.

MINING OPERATIONS, facts relating to mining—modes of working and proportionate yield—coal-cutting machines—means of ventilating mines—use of ventilating machinery—safety lamps—lighting mines by gas—drainage of mines—sinking pits—mode of raising materials—safety guides—winding machinery—underground conveyance—stone-breaking machines—mode of breaking, pulverising, and sifting various descriptions of ores.

BLASTING, facts relating to blasting under water, and blasting generally—use of gun-cotton, &c.—effects produced by large and small charges of powder—arrangement of charges.

BLAST FURNACES, shape and size—consumption of fuel—yield and quality of metal—pressure of blast—horse power required—economy of working—improvements in manufacture of iron—comparative results of hot and cold blast—increased temperature of blast—construction and working of hot-blast ovens—pyrometers—construction of tuyeres—means and results of application of waste gas from close-topped and open-topped furnaces—preparation of materials for furnace and mode of charging.

PUDDLING FURNACES, best forms and construction—worked with coal, charcoal, &c.—application of machinery to puddling.

HEATING FURNACES, best construction—consumption of fuel, and heat obtained.

CUPOLAS, construction and proportions—improvements in means of blowing—results of working, and economy of fuel.

CONVERTING FURNACES, construction of furnaces—manufacture of steel—casehardening, &c.—converting materials employed.

SMITHS' FORGES, best construction—size and material—power of blast—hot blast, &c.—construction of tuyeres.

SMITHS' FANS AND FANS generally, best construction, form of blades, &c.—facts relating to power employed and percentage of effect produced—pressure and quantity of air discharged—size and construction of air mains—mechanical ventilation and warming of public buildings.

COKE AND CHARCOAL, particulars of the best mode of making, and construction of ovens, &c.—open coking, mixtures of coal slack and other materials—evaporative power of different varieties—peat, manufacture of compressed peat.

RAILWAYS, construction of permanent way—section of rails, and mode of manufacture—mode of testing rails—experiments on rails, deflection, deterioration, and comparative durability—material and form of sleepers, size, and distances—improvements in chairs, keys, and joint fastenings,—permanent way for hot climates.

SWITCHES AND CROSSINGS, particulars of improvements, and results of working.

TURNTABLES, particulars of various constructions and improvements—engine turntables.

SIGNALS for stations and trains, and self-acting signals.

ELECTRIC TELEGRAPHS, improvements in construction and insulation—coating of wires—underground and submarine cables—mode of laying, and machinery employed.

RAILWAY CARRIAGES AND WAGONS, details of construction—proportion of dead weight.

BREAKS for carriages and wagons, best construction—self-acting breaks—continuous breaks.

BUFFERS for carriages, &c., and station buffers—different constructions and materials.

COUPLINGS for carriages and wagons—safety couplings.

SPRINGS for carriages, &c.—buffing, bearing, and draw springs—range, and deflection per ton—particulars of different constructions and materials, and results of working.

RAILWAY WHEELS, wrought-iron, cast-iron, and wood—particulars of different constructions, and results of working—comparative expense and durability—wrought-iron and steel tyres, comparative economy and results of working—mode of fixing tyres—manufacture of weldless tyres, and solid wrought-iron wheels.

RAILWAY AXLES, best description, form, material, and mode of manufacture.

PREPARATION OF PAPERS.

The Papers to be written in the third person, on foolscap paper, on one side only of each page, leaving a clear margin of an inch width on the left side. In the subjects of the papers, extracts from printed publications and questions of patent right or priority of invention are not admissible.

The Diagrams to be on a large scale and strongly coloured, so as to be clearly visible to the meeting at the time of reading the paper. Enlarged details to be added for the illustration of any particular portions, drawn full size or magnified, with the different parts strongly coloured in distinctive colours. Several explanatory diagrams drawn roughly to a large scale in dark pencil lines and strongly coloured are preferable to a few small-scale finished drawings. The scale of each diagram to be marked upon it.

INSTITUTION OF MECHANICAL ENGINEERS.

BALANCE SHEET.

For the year ending 31*st December*, 1867.

Cr.	£.	s.	d.	*Dr.*				£.	s.	d.
By Balance 31st December, 1866	4152	2	7	To Printing and Engraving Reports of Proceedings	683	18	9			
„ Subscriptions from 22 Members in arrear	66	0	0							
„ ditto from 2 Associates in arrear	6	0	0	Less Authors' copies of Papers, repaid	49	8	9	634	10	0
„ ditto from 617 Members for 1867	1851	0	0	„ Stationery and Printing				67	6	1
„ ditto from 33 Associates for 1867	99	0	0	„ Office Expenses and Petty Disbursements				98	5	3
„ ditto from 16 Graduates for 1867	32	0	0	„ Coals, Gas, and Water				18	4	3
„ ditto from 8 Members in advance for 1868	24	0	0	„ Expenses of Meetings				289	0	3
„ ditto from 1 Graduate in advance for 1868	2	0	0	„ Fittings and Repairs				16	18	5
„ ditto from 1 Life Member	30	0	0	„ Travelling Expenses				64	1	4
„ Entrance Fees from 84 New Members	168	0	0	„ Parcels				10	6	0
„ ditto from 7 New Associates	14	0	0	„ Postages				82	5	0
„ ditto from 12 New Graduates	12	0	0	„ Salaries				450	0	0
„ ditto from 1 Graduate transferred to Member	1	0	0	„ Insurance				2	8	3
„ Sale of Extra Reports	12	4	0	„ Rent and Taxes				94	7	6
„ Interest from Bank	70	19	8	Balance 31st December, 1867				4717	13	11
	£6540	6	3					£6540	6	3

(Signed) EDWARD JONES, }
WALTER MAY, } Finance Committee.

30th January, 1868.

MEMOIRS

OF MEMBERS DECEASED IN 1867.

William Carpmael was born in London on 27th February 1804, and after receiving an ordinary mercantile education became assistant in the laboratory of a chemist named Kellerman at Luton in Bedfordshire, where he remained for two years and obtained a knowledge of the rudiments of chemistry. He afterwards became a pupil of the late Professor Millington, with whom he studied for some years, and under whose supervision he prepared, amongst other engineering works, the working drawings of the bridge over the Thames at Great Marlow, the erection of which he also superintended. Subsequently he designed and erected salt works in Cheshire for the late Mr. Furnival, and these works he managed for some time. Having however become connected with the late Mr. Poole, the attorney-general's clerk of the patents, with whom he subsequently entered into partnership in 1835 as a patent agent and consulting engineer, he ceased to occupy himself with the constructive branch of engineering. The general knowledge of law which he now required, he obtained by reading with a special pleader, the late Mr. Colman of the Temple; he also qualified himself for the bar, though never called, and was a member of Lincoln's Inn. In the consideration of engineering questions he specially excelled in his rapid and firm grasp of new mechanical ideas, and in the closeness and accuracy with which he was able to define them. He became first an Associate and afterwards a Member of the Institution of Civil Engineers, and for some time was on the Council. On the formation of the Metropolitan Board of Works he was elected a member of it, and remained so until his death, taking an active part in the promotion of the project for the Main Drainage and for the Thames Embankment. He became a Member of this Institution in 1862; and died on 9th July 1867 at the age of 63.

Robert Hawthorn, of Elswick Lodge, Newcastle-on-Tyne, was born in 1797 at Dewley Burn near Walbottle Colliery, five miles west of Newcastle, his father being the engineer of the colliery. At an early age he was engaged under his father in the usual engineering work about the colliery, and occasionally in the construction of steam engines for various purposes, one special example being the pumping engine erected in 1816 at Brinkburn Colliery, which long after was considered a good specimen of his ability. In January 1817 he started works in Newcastle on his own account for the manufacture of steam engines, millwork, and cranes, &c.; and in 1820 was joined by his brother William, under the firm of R. and W. Hawthorn. In 1824 a 50 horse power double-acting condensing engine was made by them for the Plate Glass Works of Messrs. Cookson at Newcastle, which for many years was an object of much interest, and still continues to perform its duty satisfactorily and with precision. In the same year they introduced a self-acting steam travelling crane to discharge ballast from ships. In 1831 the firm commenced the manufacture of locomotive engines; and in 1835 they introduced fixed eccentrics for working the slide-valves of locomotives, and first applied them in the "Comet" engine supplied to the Newcastle and Carlisle Railway on the opening of the line in that year. Mr. Hawthorn became a Member of this Institution in 1848, and was one of the Vice-Presidents from 1864 to the time of his death, which occurred on 26th June 1867 at the age of 71.

Edward Humphrys was born at Bristol on 21st April 1810, and early devoted his attention to engineering. In 1832 he was in the service of the Dublin and London Steam Marine Company, and afterwards was manager for some time to Messrs. Rennie in London until 1848. In the following year he took the appointment of chief engineer at the Royal Dockyard, Woolwich, and after holding this position for nearly three years went to Mr. Nasmyth at Patricroft; but shortly afterwards he returned to London, and in 1852 established engineering works at Deptford Pier, devoting his attention exclusively to marine engines. Here he was very successful, many improvements being introduced by him in the details of this class of engineering; and he was largely employed by the British and chief foreign governments. His latest efforts were devoted to designing engines of 1100 horse power, with 120 inch cylinders and 4½ feet stroke, for the iron-clad turret ship "Monarch" building at Chatham. He died at Nice on 13th May 1867, aged 57 years. He was a Member of this Institution from the commencement in 1847, and for several years was on the Council.

WILLIAM JENKINS was born in 1803 at Llandewi Brefi, a small village in Cardiganshire, South Wales, where his father was a millwright. After serving an apprenticeship to his father and to Messrs. Hughes and Wren in Manchester, he was engaged under the Liverpool Dock Corporation from 1826 to 1835, having charge of the engines and machinery employed in constructing the docks at the north end; and in 1830 he was sent to superintend the construction of the cranes and tramroads in a granite quarry in Scotland, from which the granite was procured for the Liverpool docks. In 1835 he was appointed to superintend the construction of the Manchester and Bolton Railway, the canal between the same places being also under his charge; and on the opening of the railway in 1838 he was appointed superintendent and manager of both the canal and the railway. Since the amalgamation of the Manchester and Bolton with the Lancashire and Yorkshire Railway in 1845 he held the office of locomotive superintendent of the amalgamated lines up to the time of his death, which occurred on 20th November 1867 at the age of 63, after a lingering illness. He introduced a plan for the consumption of smoke in coal-burning locomotives, which was extensively adopted by the Lancashire and Yorkshire Railway and other lines. He became a Member of this Institution in 1857.

Frederick Levick was born in London on 3rd July 1803, and mmenced his career in 1825 at the Chillington Iron Works near olverhampton, and afterwards managed the Spring Vale Iron Works the same district until 1844, when he went into Monmouthshire take charge of the Blaina and Cwm Celyn Iron Works. In these rks he shortly afterwards acquired a share, and in 1858 became prietor of the whole of the works, in conjunction with his -in-law, Mr. Robert Simpson, with whom he carried on the works his death. He was one of the first to carry out successfully the isation of the waste gas from blast furnaces, which he commenced 849, and a description of the method employed for taking off the at Cwm Celyn was given to this Institution in Mr. Blackwell's er on the subject in 1852; the make of the furnaces was also gely increased by Mr. Levick about the same time to 270 tons per k from each furnace. He was the first to roll the Barlow rail, which for many years he made large quantities, rolling some as vy as 100 lbs. per yard and 27 feet long. During the 23 years t he had the control of these works he got them into a very fect condition, and brought up the make of iron to a very large ount; but in the last three years of his life he suffered very heavy erses, which told seriously on his health; and he was in a weak e for some time previous to his death, which took place at Mr. pson's residence in Buckinghamshire on 5th November 1867 at age of 64. He became a Member of this Institution in 1856.

William Ryder was born in 1808 at Turvin near Sowerby, kshire, and afterwards removed to Bury, Lancashire, where his er was employed as manager in a cotton mill. When about enteen years of age he went to Bolton, and about 1835 nmenced business there as a spindle and fly maker. In 1840 he nted the forging machine so well known in connection with his ne, for the simplification of smiths' work, which is now in general in the principal engineering works both in this country and on continent. To meet the increased business consequent upon this ntion he established works in 1844 in Bark Street, Bolton, which e subsequently enlarged to a considerable size. He died on

21st January 1867 at the age of 58, after a short illness resulting from a severe cold. He became a Member of this Institution in 1863.

Frank Shaw was born at Stockport in 1840; and after serving his apprenticeship with Mr. E. T. Bellhouse, Eagle Foundry, Manchester, he remained for some time at the same works. In March 1864 he went to Burton-upon-Trent, as draughtsman to the engineering firm of Messrs. Thornewill and Warham, and in 1866 became manager to that firm. His death took place at Anerley near London on 9th September 1867 at the age of 27. He became a Member of this Institution in 1866.

Henry Wickham Wickham, M.P. for Bradford, Yorkshire, was born in 1800, being the son of Rev. Lamplugh Hird, prebendary of York. He was one of the leading partners in the Low Moor Iron Works near Bradford, and for many years took an active part in the management of the works, but ceased to do so in 1847. In 1852 he was returned to parliament as member for Bradford, and continued to represent that borough until the time of his death, which occurred at Leamington on 23rd September 1867 at the age of 67. He was chairman of the Lancashire and Yorkshire Railway for a long period; and was also a deputy-lieutenant for the West Riding of Yorkshire, and chairman of the West Riding quarter sessions. He became a Member of this Institution in 1859.

The **Chairman** moved that the Report of the Council be received d adopted, which was passed.

The **Chairman** announced that the Ballot Lists had been duly ened, and the following Officers and Members of Council were nd to be elected for the ensuing year :—

PRESIDENT.

John Penn,	London.

VICE-PRESIDENTS.

John Anderson,	Woolwich.
Frederick J. Bramwell,	London.
Thomas Hawksley,	London.
Sampson Lloyd,	Wednesbury.
John Ramsbottom,	Crewe.
C. William Siemens,	London.

COUNCIL.

Charles Edwards Amos,	London.
William Clay,	Liverpool.
Edward A. Cowper,	London.
Edgar Gilkes,	Middlesbrough.
Thomas Greenwood,	Leeds.
George Harrison,	Birkenhead.
William Menelaus,	Dowlais.
W. Montgomerie Neilson,	Glasgow.
Charles P. Stewart,	Manchester.

PAST-PRESIDENTS.

Ex-officio permanent Members of Council.

Sir William G. Armstrong,	Newcastle-on-Tyne.
William Fairbairn,	Manchester.
James Kennedy,	Liverpool.
Robert Napier,	Glasgow.
Joseph Whitworth,	Manchester.

COUNCIL.

Members of Council remaining in office.

Alexander Allan, ...	Worcester.
Charles Cochrane, ...	Dudley.
John Fernie, ...	Leeds.
Sir Charles Fox, ...	London.
Walter May, ...	Birmingham.
John Robinson, ...	Manchester.

TREASURER.

Henry Edmunds, ...	Birmingham.

SECRETARY.

William P. Marshall, . . .	Birmingham.

The following New Members were also elected:—

MEMBERS.

Joseph Breeden, ...	Birmingham.
William Dean, ...	Wolverhampton.
Andrew Fairbairn, ...	Leeds.
Thomas Horsley, Jun., . . .	Alfreton.
Thomas Stuart Kennedy, . .	Leeds.
Lt.-Colonel Charles Vaughan Wilkieson, R.E., ...	Madras.

The following paper was then read:—

ON THE
RANSMISSION OF POWER BY WATER PRESSURE,
WITH THE APPLICATION TO
ILWAY GOODS STATIONS, FORGE AND FOUNDRY CRANES, AND BLAST-FURNACE HOISTS.

By Sir WILLIAM G. ARMSTRONG.

he employment of Water Pressure for the conveyance and
ibution of power has been extended to many new purposes
the previous paper on the subject that was communicated
ne writer to this Institution at the Newcastle Meeting in
(see Proceedings Inst. M. E. 1858, page 126.) The most
nctive feature in this mode of transmitting power is the
ratus termed the "accumulator," shown in Fig. 1, Plate 1,
h is so named because it accumulates the power exerted by the
ne in charging it. It consists of a large cast-iron cylinder A,
with a plunger B, from which a loaded weight-case C C is
nded, to give pressure to the water pumped in by the engine.
accumulator is in fact a reservoir giving pressure by load instead
elevation; and its purpose is to equalise the strain upon the
ne in cases where the quantity of power to be supplied is subject
eat and sudden variations. The load upon the plunger of the
nulator is generally such as to produce a pressure equal to that
column of water 1500 feet high, and the capacity of the cylinder
fficient to contain the largest quantity of water which can be
n from it at once by the simultaneous action of all the machines
nnection with it. The accumulator also serves as a regulator to
ngine, for when the loaded plunger rises to a certain height it
s to close a throttle-valve in the steam pipe, so as gradually to
n the speed of the engine until the descent of the loaded plunger
calls for an increased production of power. From the
nulator the water is conveyed by a pipe to the various places

where motive power is required; and in some scarce it is returned by another pipe from pumping engine to be again forced into the accu thus acts merely as a carrier of power, consequently the same as that of shafting us power of a steam engine to different parts of an

The question therefore to be considered or under what circumstances water pressure is for the transmission of power. It is not water pressure would be applicable as a su in mills and workshops where the machine compactly grouped at short distances from th they are generally continuous in their actio of water pressure is only realised in those machines to be put in motion are scattered o are intermittent in their action, and also where to be transmitted is subject to great and abrupt extended wharf, for example, every crane may at one moment, while at another time not one m shafting were used in such a case for conveying the engine would sometimes be overtaxed an without any useful effect. But with water pre of transmission, the variation of work is met by the engine acts always under a uniform load, power at times when the whole is not transmi ramifications readily carried out in laying practicable with shafting, nor can shafting be e limited distances.

Water pressure also possesses the advanta to machinery a much more controllable an than shafting. The water can be gradually tu and can be admitted as quickly or as slowly while with a shaft the motion acquired is su communicated gradually. Another advanta system is that the pipe conveying the water does not suffer any appreciable wear nor re whereas a shaft being in motion is attended with friction and consequent wear, and involves constant lubrication.

The absence of elasticity in water gives great steadiness and precision to the movements of machines actuated by water pressure; but on the other hand, water being incapable of expanding like steam in a cylinder, the quantity expended is not proportionate to the load. Thus a machine propelled by hydraulic pressure measures off the same quantity of water, whatever may be the resistance overcome; and therefore when the machine is inadequately loaded the expenditure is more than equivalent to the effect produced. This loss of power may in a great measure be obviated by making the machines with variable powers; but the simplicity of single-power machines renders them preferable in many cases, notwithstanding their greater expenditure of power. In fact for the purposes to which water pressure is most usually applied, safety, simplicity, and general convenience are more to be considered than economy of power, because owing to the intermittent character of the work the required quantity of power is not large in the aggregate. It has also to be recollected that, although power is sacrificed by that very property in water which gives so much steadiness and safety to its action, yet the favourable condition under which a steam engine works when pumping against a constant head, as in charging an accumulator, cheapens the production of the power, and compensates for its more lavish application.

In connection with the non-elastic character of water, it will be observed that its incompressibility in the cylinder of the machines would, if not provided against, cause very injurious shocks and strains to the machinery, by suddenly arresting the momentum of the moving parts on the closing of the outlet passages. To obviate this liability, nearly all varieties of water-pressure machines adapted for rapid action require the introduction of what are termed "relief" valves. These have already been fully described in the writer's previous paper on water-pressure machinery; and it is therefore only necessary on this occasion to describe them as consisting of small clacks D D, as shown in Fig. 2, Plate 1, opening against the pressure

P in the supply pipes, and yielding to any back pressure on the pistons that exceeds the accumulator pressure. In the drawing P P represents the pressure, and E E the exhaust passages.

With a pressure equal to a column of water 1500 feet high, the loss of head by friction in the pipes forms a very inconsiderable deduction from the entire column; and the pressure may therefore be conveyed without any serious sacrifice to great distances from the engine. In some instances the length of the pressure pipes has been extended to more than two miles without any apparent decrease of effect; but in all cases where the pipe is very long it is desirable to apply an accumulator at each extremity, in order to charge the pipe from both ends. The most advantageous pressure of water for practical use seems to be that mentioned above, namely 1500 feet or about 700 lbs. per square inch. By increasing the pressure the size of the pipes and of all parts of the apparatus is lessened; but on exceeding the above limit a difficulty begins to be felt in preventing leakage and keeping the valves and packings in order; and this objection more than counterbalances the advantage of reducing the size of the apparatus.

Compressed air has often been proposed, and in some instances tried, as a medium for the transmission of power. Being elastic it has an advantage over water in accommodating its volume and consequently its expenditure to the load on the piston; but on the other hand it does not give back all the power put into it by the engine, because practically it cannot be used expansively to the full extent of its previous compression. In order to return all its acquired power, the air must undergo no throttling, and must be discharged from the cylinder in which it acts at the density of the atmosphere; and as these conditions are impracticable, the loss from elasticity in air is probably as great as that from the absence of elasticity in water. But the use of compressed air is subject to a far more serious source of waste by leakage, which in the case of air is very difficult to detect; and in an extended system of pipes and machines, requiring a multitude of joints, valves, and fitting surfaces, the leakage of the air must form an insurmountable difficulty. Moreover the elasticity of air deprives the machines to which it is applied of that perfect steadiness and precision which is rded by the incompressibility of water. Nor is any advantage to gained by adopting the converse process of exhausting the air ead of compressing it, since the difficulties which apply to the one e are equally incident to the other.

The purposes to which water pressure has been applied as a ns of transmitting power are exceedingly numerous; in fact in ost every case where manual labour is used as a mere motive er it may be superseded by engine power transmitted by means water pressure. The widest application of this system is in ks, where the water-pressure machinery is now most extensively d in England for the purpose of opening and closing the gates, ng bridges, and sluices, and also for hauling ships through the ks and discharging and warehousing cargoes. It is also very erally employed in the various operations connected with the ment and discharge of coal; and the mechanical arrangements lied to meet the different conditions under which these rations have to be performed are very various, and in some es necessarily very elaborate. Perhaps the case of greatest elty in this branch of the application of water pressure is that machine erected for the purpose of shipping coals at Goole Docks, the river Humber, where barges containing 32 tons of coal are ted into a cradle, and then lifted bodily to a considerable height turned over into a shoot, which delivers the coal into a ship gside.

Water pressure as a medium for transmitting power has not yet n very extensively employed on the continent. In France it n use at Marseilles, at Rouen, and at the Goods Station of the is and Lyons Railway in Paris, for the purpose of loading and oading the wagons and also for hauling them in the station d. The machinery at this station affords a good example of the lication of the principle to railway goods traffic, and may efore be selected for description.

The machines comprise fifteen single-power hydraulic platform nes to lift 1½ tons; and three double-power similar cranes, to lift ons with the lower power, and 3 tons with the higher power;

also two hydraulic engines for driving capstan heads for hauling trucks.

The Single-power Cranes are represented in Figs. 6 and 7, Plate 3. They are adapted to turn as well as to lift and lower by the water pressure. The jib is a fixture to the crane pillar A, which is made to revolve by means of a chain passing round the cupped wheel B and worked by a pair of hydraulic presses C C. The diameter of the ram of each turning press C is 4 inches, and the length of stroke is 3 ft. 8 ins., which is doubled by passing the chain over a pulley at the end of the ram and fixing the extremity to the cylinder. The ram of the lifting press D is 5¾ inches diameter, and has a stroke of 4 ft. 8 ins., and the motion is multiplied four times by means of pulleys. The chain is conveyed upwards through the centre of the pillar A and thence over the end of the jib. The lifting cylinder D is placed at an angle, to facilitate the overhauling of the chain. The valves for lifting and lowering and for turning are slide valves, the lifting and lowering valve having two ports, and the turning valve three ports. Each valve is worked by a lever E passing through the platform, the two levers being placed at a proper distance apart so as to be worked by a man standing between them with a hand on each lever. To provide against the crane jib slewing round beyond the range of the turning presses, the turning valve is made to close by a self-acting arrangement at each extremity of the range.

The Double-power Crane is of the same general construction as the single-power; but instead of a simple hydraulic press with ram for lifting, a bored cylinder with a combined ram and piston is applied, as shown in Figs. 3 and 4, Plate 2. For the lower power the pressure is admitted upon both sides of the piston A, and therefore virtually acts only upon the ram B, which is half the area of the piston. For the higher power the front side of the piston is open to the exhaust E, leaving the pressure P to act on the back only, and the effect is then proportionate to the area of the piston, which is twice that of the ram. This alternative action is determined by the intervention of an extra valve C, Figs. 3 and 5; when this valve is opened, as shown in Fig. 5, the pressure P has access to both sides of the piston, and the lower power is then obtained; while for the higher power the valve C is closed, and the exhaust valve D is opened, whereby the front side of the piston is kept constantly open to the exhaust E. In cases where three powers are required, three simple hydraulic presses are commonly used, which act either singly or in combination; but the same effect may be obtained with a bored cylinder and piston combined with two concentric rams, the external ram being secured by a pall when its action is not required, and the internal ram acting through a water-tight gland in the outer ram. In this case the lowest power is obtained by admitting the water only on the front side of the piston, whence it enters into the interior of the larger ram through a hole near the piston, and forces out the inner or smaller ram. The second power is obtained by admitting the water to both sides of the piston; and the highest power is brought into action by opening the front side of the piston to the exhaust, while the pressure operates on the back of the piston.

The Capstan Engines used at this railway station have each two oscillating cylinders with combined rams and pistons, working cranks at right angles; on the front side of the piston, which is half the entire area, the pressure is constant, and the back communicates alternately with the pressure and the exhaust. The engine therefore acts by a difference of pressure in one direction and by a positive pressure in the other, the effective pressure being equal in both cases; and the action is governed by a two-port slide-valve worked direct from the trunnion. In these engines, as well as in the cranes, "relief" valves are applied to prevent concussion from the water shut in.

Since the platform cranes of the Paris and Lyons Railway were constructed, a new arrangement of platform crane has been introduced, in which the lifting cylinder is arranged so as to form the crane pillar. An example of this kind of crane is shown in Fig. 8, Plate 4, where A is the lifting ram acting upon a chain B, which gives a twofold motion to a double-pulley running-block C. A corresponding double-pulley block D is fixed to the base of the jib, and over these pulleys the lifting chain passes four times, so that the range of the ram is multiplied altogether eight times at the outer end of the chain.

Another modification of the same kind of arrangement is exhibited in Figs. 9 and 10, Plate 5, where the crane pillar is carried in top and bottom bearings, and the lifting press A is placed between the two cheeks of the pillar. In this case there is no turning power, and the lifting valve B as well as the press is attached to the crane pillar, as shown to a larger scale in the section, Fig. 11, Plate 6. This is the simplest and cheapest form of hydraulic crane which is made. In all cases of cranes containing the lifting press in the pillar, the water is admitted through the pivot at the bottom, which is made water-tight by means of a cupped leather. For cranes of very high power, where only slow motions are required, it is now usual to employ the ordinary gearing of a steam crane, and to apply the water pressure by means of a small hydraulic engine fixed in the framework of the crane.

Hydraulic cranes have of late years been introduced with great advantage at the Elswick Works, both in the Forge and in the Foundry. In the forge they are applied to the service of a 12 ton hammer, and by this means forgings ranging in weight up to 20 tons are manipulated under the hammer with perfect precision and great saving of time and labour. In the foundry they are so applied as to command every part of the floor, and thus wholly to supersede manual labour for every purpose of lifting and carrying. The form of crane used in each of these departments is the same, and is represented in Figs. 12 and 13, Plate 7. The jib and pillar of the crane are of wrought iron, and revolve in top and bottom bearings. The crane has three motions, namely lifting, turning, and traversing, all of which are effected by hydraulic power. The lifting cylinder A is made of double power by the ram and piston arrangement before described, the highest power being equal to 20 tons; the ram is 11 inches diameter and the piston $15\frac{1}{2}$ inches diameter, the length of stroke being 6 ft. 8 ins. The turning cylinders B are applied in the usual manner at the foot of the crane pillar, the rams being each $4\frac{1}{4}$ inches diameter with 5 feet stroke; and both the lifting and the turning cylinders with their valves are fixed in a chamber beneath the level of the floor. A three-port slide-valve is used for the two ng cylinders, and mitre valves for the lifting cylinder. The from the lifting cylinder is carried upwards through the crane , bending over a sheave C at the top of the pillar, and passes ssively over the pulleys of the travelling carriage D and the ing block E, and is finally made fast at the extremity F of the For the purpose of overhauling the ram of the lifting press, a press is placed between the two turning presses B; and the auling action is effected by a chain and sheaves multiplying times, the outer end of the chain being attached to the sliding of the lifting ram at I. The pressure in the overhauling press nstant, and its action is therefore equivalent to that of a erweight; the ram is 4½ inches diameter with 3 ft. 5 ins. stroke. effecting the traversing motion of the load suspended at the G, the travelling carriage D is hauled inwards and outwards by presses H fixed to the back of the crane pillar, and connected by s with the travelling carriage; the ram of each press is 5½ inches eter with 4 ft. 7 ins. stroke. The alternating action of these es, which is precisely the same as that of the presses B used for turning motion, is regulated by a three-port slide-valve K hed to the front of the pillar, with a lever at each side for ing it. The water is supplied to and discharged from these es by two pipes which pass through the top bearing of the , and the connection between the valve and these pipes is effected ch case by a trunnion joint at J J.

nother novel purpose to which hydraulic pressure has recently applied is the raising of the materials required for feeding Furnaces. The great increase in the height, size, and uctive power of modern blast furnaces has necessitated a great ase of speed and power in the lift; and the employment of r-pressure machines has fully satisfied these requirements. The ratus employed for this purpose is represented in Fig. 14, 8. The framework of the hoist is constructed of cast-iron nns supported by wrought-iron bracing. Two guided cages A A used for receiving the barrows containing the materials to be d to the furnace mouth; and two separate lifting-presses B B, for each cage, are fixed in an inverted position against opposite sides of the framing, the ram of each press being 11½ inches diameter with a stroke of 8 feet. The lifting chain makes five turns over the pulleys C C of each press, so as to multiply the stroke tenfold, and is carried up over a sheave D at the top of the framing, and thence descends to the cage to which it is attached. The two cages are connected with each other by a wire rope which passes over a sheave E at the top of the framework, so that they balance each other, the one being lowered while the other is raised. The cages lift two barrows at a time, weighing with their contents 1½ tons, and they are hoisted to the top at the rate of 4 feet per second; a much higher speed could be attained by increasing the size of the valves and pipes to the required extent. A three-port slide-valve is used for working the two presses, and admits the water to the one press while it discharges it from the other. The valve is worked at the bottom, but a rope is provided to enable it to be worked from the top as well. An arrangement is applied by which the cages gradually close the valve at the termination of each lift, and thereby ensure a soft and gradual cessation of the motion; and a safety apparatus is attached to each cage, to arrest its fall by gripping the guide bars in the event of the breakage of a chain.

Illustrations of the application of water power to machines of this class might be greatly multiplied. In all however the leading features and principles would be the same, and the new examples would merely show modifications of the same general mechanical arrangement.

The Chairman observed that the transmission of power by water pressure was a comparatively new branch of mechanical engineering, and not many years ago it had been doubted how far such an application of power could be brought to a successful issue. The principle however had gradually been more and more developed, chiefly owing to the energy and perseverance of the author of the paper just read, who was unfortunately prevented from being present at the meeting. In almost every instance in which water pressure had been adopted it had been found one of the simplest and most complete methods of transmitting power, particularly in its application to cranes and hoists; and the adaptations of the principle to a variety of mechanical purposes appeared likely to increase continually in usefulness. As the water pressure machinery was now so largely adopted on wharves and in other exposed situations, he enquired whether much inconvenience had been experienced from the freezing of the water in the pipes and in the cylinders during severe weather.

Mr. G. HUTCHINSON, who attended the meeting in the absence of Sir William Armstrong, replied that there had been some few cases of cylinders being burst by the freezing of the water, but these had been very few indeed; out of as many as 5000 or 6000 hydraulic cylinders now in use in various parts of this country and abroad, there had been only six or eight instances he believed of cylinders being broken by the frost. As a precaution against such accidents, it was general to introduce a jet of gas into the chamber in which the hydraulic cylinders were placed; and even in a large chamber a very small jet of gas was found sufficient to prevent the water freezing. Where the cylinders were unavoidably exposed to the frost, without being covered in, it was necessary to provide means of draining them empty whenever they had to be left standing; because if the ram happened ever to be out to the full extent of its stroke, and the water were then to freeze, it would be almost certain to burst the cylinder, the ram being prevented by stops from moving any further. Of course if the ram were not at the end of its stroke it would yield to the expansion of the water in freezing, and so save the cylinder from being burst; and therefore if no means of draining the cylinder were provided, it was necessary in such cases to take care that the machine was never left standing with the ram fully out.

Mr. E. A. COWPER enquired whether a mixture of methylated spirit with the water had been tried for preventing the water from freezing. He knew a mixture of 5 per cent. of methylated spirit had been employed in similar cases, and had been found very effectual for the purpose, as that proportion of spirit was quite sufficient to prevent water from freezing with any degree of cold ordinarily experienced in this country. In some of the oil mills at Hull the hydraulic presses were worked entirely with oil instead of water.

Mr. Hutchinson said it was not usual to employ a mixture of methylated spirit, although there were a few instances in which it had been adopted. One case in particular was that of a hydraulic drawbridge on the South Wales Railway near Carmarthen, constructed sixteen or eighteen years ago, and the spirit mixed with the water was found to have the desired effect in preventing freezing; the bridge was lifted and drawn backwards and forwards by water pumped into an accumulator by hand labour. That was the only instance however in which the plan had been used for a bridge, as in bridges generally the hydraulic machinery was either sufficiently well protected from frost, or else a gas jet was introduced into the chamber containing the water cylinders. With regard to the use of oil, it was employed in working the hydraulic cranes at the North Eastern Railway station at Hull, but only in a small quantity mixed with the water, for the purpose of better lubricating the slide-valve faces.

The Chairman enquired what kind of packing was generally used for the rams and pistons of the hydraulic machinery; whether it was hemp packing or cupped leathers.

Mr. Hutchinson replied that for the packing of rams generally it was preferred to use hemp; for although in the first instance the hemp produced considerably more friction than a cupped leather would do, yet when once consolidated a hemp packing worked with very little friction and was very durable. But for packing pistons in cylinders of double power, cupped leathers were preferable, on account of the difficulty of getting at the piston to screw up a hemp packing or renew the packing when necessary; whereas with a ram there was only the external stuffing-box to be packed, which was easily accomplished at any time. Another objection to a hemp packing for pistons was that the strands of hemp, especially when new, were partially worn off in the process of working, and the loose bits of hemp getting into the valves were liable to foul them, causing kage and other inconveniences. For these reasons cupped leathers re generally used for the packing of pistons, except where a hemp cking was particularly desired; but for the rams hemp packing s invariably employed.

Mr. E. A. Cowper considered they were greatly indebted for the luable details given in the paper respecting the successful working the hydraulic machinery; and he fully concurred in the advantages t would result from conveying power by means of water pressure a great distance; the successful application of the plan to a tance as great as two miles was a practical result of great portance. In comparing water with air as a medium for the nsmission of power, it must be admitted that air was exceedingly ful for conveying the power required to work coal-cutting or nelling machines, where it would be impossible with water to ain anything like 200 to 300 strokes per minute of the tool, on ount of the entire absence of elasticity. But on the other hand use of air was attended with several disadvantages, the most portant of which was perhaps the amount of leakage that took ce without being detected, as mentioned in the paper. There s also another inevitable source of loss with air, which had not n referred to; and this was that in the compression of the air large amount of heat developed by the compressing engine s all dissipated and lost before the compressed air reached the nt of application, so that the actual volume of air was less after had traversed the length of the connecting pipes than in the apressing engine, in addition to which the air cooled in expanding. sides this, in compressing there was the resistance of the full apression figure against the engine, whilst in using the compressed it was impossible to obtain the full value of the expansion figure; l an indicator diagram taken from the machine worked by the apressed air would show a considerably smaller amount of power n the corresponding diagram from the air-compressing cylinder, s proving a proportionate loss of power in the use of the apressed air. Air however, particularly in a cool and perfectly h state, was of the greatest value in mines and tunnels; and in se and some other cases was much to be preferred to water power. It would therefore be required to be determined for each separate case of transmitting power to a distance, whether the advantages preponderated in favour of air, or whether water was better adapted for the purpose in view.

The advantages of employing water pressure for conveying power to considerable distances he had himself realised many years ago in the case of a forge, having adopted that plan for working a number of different machines used in the manufacture of iron, for pressing, bending, and punching, &c.; and there was no doubt a great advantage also in the extremely steady motion that was obtained by the use of water. As a simple and compact form of reservoir for giving the required pressure he had employed a cylinder fitted with a vertical differential ram, working through stuffing-boxes at top and bottom, and loaded with a weight sufficient to produce the pressure needed; the upper half of the length of the ram was 4 inches diameter and the lower half 3 inches diameter, the length of stroke being about 10 feet. An engine was kept constantly pumping water into this reservoir, and the quantity of water accumulated under pressure by this means was found quite sufficient to work a number of different machines situated in various parts of the works. This was the method employed for working a very large punching press used in punching out the flat links for the Kief suspension bridge in Russia; the links were each 10 inches by 1 inch in the body, and had one large eye at one end and a long slot for adjusting keys at the other, and were 7 feet 6 inches long and about 17 inches over the eyes; the whole was punched hot out of a large plate in about 3 seconds by one stroke of the press, on simply turning a cock to admit the water pressure. The idea of accumulating the pressure in a reservoir in this manner had been suggested to him by seeing the plan adopted in a paper mill, where it was the practice to save the trouble of charging independently each of the hydraulic presses employed for pressing the paper, by connecting all the presses with one loaded press, and using this as an accumulator for storing water, keeping it constantly charged by the pumps, ready for working the other presses; by this arrangement the convenience of an accumulator was obtained for working the other presses. A valuable description had been ven in the paper of a variety of applications of water pressure for ing weights; and another purpose, for which it was peculiarly well apted, was the testing of girders, where the steadiness of motion tained was of great value in arriving at accurate results.

Mr. F. W. Webb enquired with regard to the hydraulic lift for st furnaces, whether there was any communication between the o hydraulic cylinders working the hoist, in order to make them vays work simultaneously, so as to avoid any risk of disarranging e wire rope connecting the two cages of the hoist, by starting one inder before the other.

Mr. Hutchinson explained that both the cylinders were controlled conjunction by a single handle, which worked an ordinary three-port de-valve, like the slide-valve of a steam engine; so that when the essure was admitted to one of the cylinders, the other was at the ne time opened to the exhaust.

The Chairman enquired what was the greatest height to which e blast-furnace hoist had been made to lift.

Mr. Hutchinson replied that the highest hoist which had been de was for some blast furnaces at Ferryhill, where the height of was 102 feet. The hoist shown in the drawings was for a lift of feet height.

Mr. W. Clay remarked that, having had to design some rather werful hydraulic machinery for the Mersey Iron Works, Liverpool, had introduced some arrangements which he had not met with ewhere in the employment of water pressure. There were two s of 20 and 30 feet height for raising materials at the works, each pable of lifting a load of 20 tons; and the siding along which the gons were brought to one of the lifts being at an angle of 30° to a line of rails at the upper level, the circular platform of the lift, feet in diameter, was turned round through the angle of 30° ring its ascent or descent, by a rifle motion giving it a spiral vement in rising or falling, so that the lift itself acted as a rntable, instead of requiring a separate turntable on the platform the lift.

It had also occurred to him that, if the weight of the descending ds on the lifts could be utilised, a saving would be effected of nearly half the power otherwise required for working the lifts. For as the accumulator working the lifts had to be weighted to a pressure of 600 lbs. per square inch for raising a load of 20 tons on the lift, there would be a loss of 300 lbs. of pressure at each time of lowering an empty wagon of 10 tons weight. In order therefore to turn to advantage the pressure exerted by the descending loads, it was only necessary to open a communication between the cylinders of the descending lifts and the suction pipe of the double-acting pumps charging the accumulator, instead of running the water from the lifts into an open reservoir as was usually done; by this means the pressure due to the descending load, whatever it might be, was utilised in assisting the pumps to charge the accumulator. For example, in the case of lowering a wagon of 10 tons weight, representing a pressure of say 300 lbs. per square inch, the valve was opened admitting the water at a pressure of 300 lbs. per square inch from the lift to the pumps, thus assisting them to that extent in charging the accumulator which was weighted to 600 lbs. per square inch, and thereby saving the use of one half the steam power otherwise required. The result of this arrangement was that, instead of requiring 45 lbs. steam to work the engine for charging the accumulator, a steam pressure of only 25 lbs. was found sufficient for keeping it charged; and although there would have been a deficiency of boiler power for working the lifts, according to the usual plan of running to waste all the water discharged in lowering, yet by this method of utilising the effect of the descending loads there was always an ample supply of steam maintained for keeping the accumulator fully charged, the steam engine having in fact only half the work to do. There was of course some little difficulty in the application of this plan in cases where a number of cranes or lifts were all connected to the same discharge pipe, because if a heavy load were being lowered, a lighter one would have to wait and could not begin to descend till the heavier one had reached the bottom, since the cylinders of the two descending lifts would at that time be put in communication with each other through the discharge pipe. Moreover the lighter loads would be retarded in their descent as compared with the heavier ones, because the rate at which the pumps worked and took water from the descending lift limited the speed of descent; and rate would be slower when less aid was given by a lighter load. rision was also made by suitable valves for turning the water 1 the descending lifts into an open reservoir in the usual manner, sirable at any time.

This arrangement had proved so successful in economising power, he had applied the same plan also to the hydraulic machinery loyed in the Bessemer works at the same place, in the original gning of which there had not been sufficient power provided for king all the cranes for the ladles and moulds with the required dity, and it had been found that the casting pits could not be red quickly enough to get through all the work that had to be e. By adopting this simple method however of utilising all the ending weights, he had now obtained power enough for the work ired; and the whole cost of the alterations made for the purpose been very trifling.

Mr. HUTCHINSON said that the principle of utilising the weight descending load had been applied for several years past in the raulic machinery used for loading coals into ships, where the coal delivered alongside at a high level and had to be lowered down the ships to a depth of perhaps 50 or 60 feet. An instance of sort was to be seen at Newport in Monmouthshire, where each containing about 2 tons of coal was first lifted clear off the truck hydraulic cylinder of very short range but considerable diameter, was then allowed to descend by its own weight; by its descent m of small diameter was forced back against the pressure of the mulator, but when the coal had been discharged, the ram had cient power to raise the empty box again. In other cases, such oists for lifting wagons, where it was desired to economise power, nall auxiliary ram was employed, which was forced back against accumulator pressure by the descent of the empty hoist; or else ounterbalance weight was used, not quite as heavy as the cradle ne hoist.

The idea of turning round the platform of a hoist during its nt and descent had been carried out some years ago in two ts at Grimsby. In these hoists two vertical guides were used, with oblique grooves cast upon their inner faces, so that the face of the guide would represent a segment cut out of a long spirally-rifled cylinder; and corresponding oblique teeth fitted round the circumference of the circular platform made the platform twist round in ascending and descending, by sliding in the rifle grooves.

Mr. E. HOWARD enquired what was the minimum pressure of water at which the hydraulic cranes and other machines were found to work satisfactorily; there must of course be a certain amount of pressure necessary to overcome the friction.

Mr. HUTCHINSON replied that hydraulic cranes had been made to work at as low a pressure as only 40 to 50 lbs. per square inch, but in those cases the cylinders were necessarily very large and very expensive, particularly if the load to be lifted was considerable or the height of lift great. Where the pressure had to be produced artificially by the aid of an accumulator, it had been found in general that the pressure named in the paper, of 700 lbs. per square inch, was the most convenient. In some instances the pressure had been increased up to 1000 lbs. per square inch, as in the case of the chain-testing works at Birkenhead, where that pressure had been adopted for four hoists employed for loading vessels, and originally isolated from the rest of the works. Subsequently however considerable inconvenience had arisen in consequence; for the hydraulic machinery in the rest of the works having been extended, at the more usual pressure of 700 lbs., it had now become necessary to combine the two systems, and much difficulty and trouble had been occasioned from having to deal with two different pressures. The principal objection that had been experienced in going to a higher pressure than 700 lbs. was that the rams and their attachments became then inconveniently small. A certain diameter and width of groove was necessary for the sheaves, to suit the size of the chains employed, and a proportionate size of pin and area of rubbing surface was required to ensure durability; the crosshead therefore had to be made not less than a certain size, and this involved also a certain minimum diameter for the ram. The same objection as to the size of the parts did not apply to reducing the working pressure somewhat below the standard of 700 lbs., and in some cases hydraulic machinery had been constructed for a pressure of 500 lbs. per square inch, and worked at that pressure without inconvenience. At the London Docks a pressure of 600 lbs. had been adopted in the first instance; but a second set of machinery having afterwards been put down at some distance with the higher pressure of 700 lbs., the subsequent combination of the two pressures had proved very inconvenient. On these accounts therefore 700 lbs. per square inch had been decided upon as the standard pressure for all hydraulic machinery, and was now invariably employed.

Mr. F. J. **Bramwell** mentioned that a low-pressure hydraulic hoist had been put up at the new Westminster Palace Hotel, which was worked by the pressure of water from a tank at the top of the hoist, the pressure being equal to about 35 to 40 lbs. per square inch; and the tank was supplied with water from the ordinary street main. The piston of the hoist was 20 inches diameter with 10 feet stroke, and the height of lift was about 56 feet; the stroke of the piston was multiplied 5½ times to equal that of the lift, by means of a rack working a pinion on the shaft of a large pulley. The cost of the water was said to be 1*d.* per lift for the full height.

With respect to the question of transmitting power from a common central source to a number of cranes, it might be mentioned that as long ago as the opening of the St. Katherine's Docks in London it was intended to employ the pneumatic or exhaustion system for working the cranes, by means of engines attached to them and driven by the pressure of the atmosphere working against a partial vacuum, the connection to the central motive power being effected by exhaust mains; but a long delay that occurred in the construction of the trial crane led to the abandonment of the system at those docks, as the common cranes had in the meantime been fixed. The exhaustion system was useful under certain circumstances and had been extensively applied in a variety of ingenious ways; there were however objections to it, one of which was the small pressure per inch that could be obtained on the working pistons, and the consequent large diameter of the cylinders. This defect was increased if it were sought to work expansively; but without expansion there must clearly be a great loss of power in these cases, as the exhausting air-pumps would show a figure like an expansion diagram and would require the power due to such a diagram for working them; and therefore if the pneumatic cylinders were not worked with an expansion curve practically corresponding with that of the exhausting pumps, a serious loss of power would ensue. For these reasons he did not think that for general purposes the pneumatic or exhaustion system would ever successfully compete with the use of water pressure for the transmission of power; and in the great majority of cases where power had to be transmitted from a distance, water pressure was decidedly superior to the use of air whether by exhaustion or compression. In the particular instance however of working underground machinery, as in collieries, air had the advantage of answering the double purpose of conveying power to a distance and of aiding in the ventilation of the workings; in such situations also the discharge of water from hydraulic machinery might be very undesirable.

Mr. R. Mallet observed that it was a remarkable circumstance that Bramah, the inventor of the hydraulic press, had suggested as early as 1802 the application of the same principle for working the cranes on the dock quays at Dublin and in the warehouses of the London Docks, as was shown by the accompanying autograph letter.* This showed that Bramah had distinctly seen the great scope for uture expansion of the principle; but he had been too much in dvance of the time for his ideas to be practically developed during is lifetime to so great an extent as they had since been by the very ngenious and perfect arrangements described in the paper now read.

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* Extract from autograph letter of Joseph Bramah to Robert Mallet, dated London 10 Nov. 1802, the original of which was shown to the Meeting and a photographic duplicate presented:—

"I have also now applied it" (the Hydraulic Press) "with the most "surprising effect to every sort of crane for raising and lowering goods in and "out of warehouses. So complete is the device, that I will engage to erect a "steam engine in any part of Dublin, and from it convey motion and power to "all the cranes on the keys and elsewhere, by which goods of any weight may "be raised at one third of the usual cost. This I do by the simple communication "of a pipe, just the same as I should do to supply such premises with water. I "have a crane on my own premises which astonishes every person to whom it "has been shown, as they see the goods ascend and descend 15 or 20 times in a "minute to the height of 18 or 20 feet, and at the same time it is impossible for "any person unacquainted with the principle to discover how or where the "power comes from."

The Chairman remarked that unquestionably the principle of Bramah's hydraulic press, which had gained a world-wide fame, ormed the basis of the present applications of water pressure; but t was only within the last few years that the employment of water pressure had been systematically worked out as a means for the transmission of power.

He moved a vote of thanks to Sir William Armstrong for his paper, which was passed, and also to Mr. Hutchinson for the additional xplanations which he had given.

A paper was then read "On the Allen Engine and Governor," by Mr. Charles T. Porter, of Manchester; and the discussion was djourned to the next meeting. (See Proceedings April 1868.)

The Meeting then terminated; and in the evening a number of he Members dined together in celebration of the Twenty-first nniversary of the Institution.

PROCEEDINGS.

30 April, 1868.

The General Meeting of the Members was held in the Lecture atre of the Midland Institute, Birmingham, on Thursday, 30th il, 1868; Thomas Hawksley, Esq., Vice-President, in the ir.

The Minutes of the last Meeting were read and confirmed.

The Chairman announced that the Ballot Lists had been duly ned, and the following New Members had been found to be ted :—

MEMBERS.

Thomas Carrington, Jun.,	Sheffield.
Henry Wheeler Davis,	London.
Enoch Horton,	Darlaston.
Robert Jobson,	Dudley.
William Gregory Norris,	Coalbrookdale.
Henry Parker,	Kurrachee, India.
William Rogers,	Adelaide, Australia.
George Robert Stephenson,	London.
Frederick Bevoley Vallance,	Greenwich.
Peter Ormerod Whitehead,	Manchester.

GRADUATE.

William Henry Dugard,	Birmingham.

The Chairman announced that the following communication had n received from the Patent Office, requesting the Institution to inate gentlemen for the appointment to be made by Government ne out of three additional Commissioners of Patents :—

Patent Office, 28th April, 1868.

Dear Sir,

I have been directed by the Lord Chancellor and the Master of the Rolls to transmit to you copies of a Memorial presented to the Master of the Rolls on the 20th ult., and his Lordship's reply to Mr. Dillwyn dated 31st March; and to request that you will submit them to the Members of the Institution of Mechanical Engineers, in order that they may be pleased to nominate gentlemen with the requisite qualifications for the proposed appointments.

Yours truly,

B. WOODCROFT,

Clerk to the Commissioners of Patents.

The Secretary,
Institution of Mechanical Engineers.

(Copy of the Memorial.)

TO THE RIGHT HONOURABLE THE LORD ROMILLY,
MASTER OF THE ROLLS.

My Lord,

The great use of Patents is to make known the inventions, processes, and secrets of others. It is therefore highly important that the mass of information accumulated at the Patent Office should be made available, so as to make known as far as possible all inventions and modes of manufacture for the benefit of the country. The advantage of so doing would be immense, and would help to keep the manufactures of this country in advance of others. Action in this direction on the part of the authorities has been prayed for in every memorial that has been presented.

One of the first Memorials was presented by the Institution of Mechanical Engineers, with Mr. Robert Stephenson as President at its head. This was presented in 1853 to the Right Honourable Frederick Lord Chelmsford, Lord High Chancellor of Great Britain, the Right Honourable Sir John Romilly, Master of the Rolls, Sir

Fitzroy Kelly, Her Majesty's Attorney General, and Sir Hugh McCalmont Cairns, Her Majesty's Solicitor General; and prayed for greater facilities being given to persons making enquiries in any branch of knowledge at the Patent Office.

The second Memorial in 1862 was presented to the Right Honourable Sir John Romilly. It prayed amongst other things for "a building as an Office for Patents, including in it a complete library, a commodious reading room, and suitable offices for a proper staff of clerks and others to prepare well-digested and numerous abstracts and abridgments of inventions and processes, made public either by the specifications of patents or otherwise, and whether English or Foreign."

A third Memorial was presented to Sir John Romilly in 1864. It prayed not only that the efficiency of the office should be increased, but called the attention of the Commissioners to recent reductions in the staff and its disorganised state; which staff was "utterly inadequate to satisfy the requirements of persons seeking information among the very numerous works contained there." The memorialists went on to state that "they had entertained the hope that, so far from a reduction being made, there would have been an increase ordered to such an extent as would have enabled the abridgments of the specifications in the various branches of art (which abridgments were commenced about seven years ago) to be pushed vigorously forward, so as to complete the abstracting of the whole of the original specifications, and to keep up those abstracts from year to year as new matter is furnished. Your memorialists feel it is hardly possible to overrate the advantages to be derived by the public from a complete and intelligent system of abstracts; and they venture to urge upon the consideration of the Commissioners the necessity of at once providing a sufficient number of qualified persons (to be under the entire control of the scientific officer appointed by the Commissioners to superintend the specifications) to assist that officer in preparing such abstracts, and also to collect and epitomise scientific information generally."

The President and Members of the Institution of Mechanical Engineers addressed a Memorial in 1864 to the Right Honourable

Lord Westbury, then Lord Chancellor, bringing under his Lordship's notice the fact "that very great loss and delay are occasioned to manufacturers, inventors, and others, by the want of a complete classification and the prompt Indexing of all inventions, whether patented or not, Foreign as well as English. Such a systematic arrangement as is needed is quite within the compass of an efficient staff of officers possessed of technical knowledge, and could be at once proceeded with; the state of inventions could then be ascertained, and the common case of several persons patenting the same thing would be avoided."

In 1864 a Select Committee of the House of Commons enquired at great length into the working of the Patent Office; and reported, in accordance with the general tenor of the evidence, that much more was required to be done at the Patent Office to render it efficient; that more attendants were required, and "that the want of increased accommodation was so much felt as to prejudice the due administration of the Patent Law" (paragraphs 3 and 4 of Report; answers 10 to 13, 18 to 21, 658 to 662, 667, 817, 863, 1038, and 1039 of Evidence).

We merely allude to the opinions expressed by the Select Committee of the House of Commons, scientific men, manufacturers, engineers, and inventors, as the various memorials and other documents are in the possession of the Commissioners of Patents; but we would further mention that the various Commissioners of Patents have from the year 1858 reported from time to time to the Lords of the Treasury that great improvements were wanted and a good building urgently required for the purposes of the Patent Office.

In conclusion we beg to state that it is our decided opinion, and that of many of those who have signed various memorials, that it would conduce greatly to the progress of manufactures and the advancement of commerce, if the large stock of knowledge of inventions and processes, both patented and open, stored at the Patent Office, were made available to manufacturers and the public generally; and this your petitioners believe would best be compassed, if Her Majesty were graciously pleased to appoint that "other person as Commissioner of Patents," as contemplated by the Patent Law Amendment Act of 1852, and if the staff at the Patent Office were augmented by the addition of a sufficient number of persons, possessed of good technical knowledge and well able to abstract all specifications as they came in daily, so that they might at once be entered into an efficient Subject-Matter Index, which would give a true indication of what was in the specifications. In addition to this of course the large number of specifications already at the office would require to be abstracted and entered in a similar manner in a new edition of subject-matter indexes, that would really indicate what was contained in each specification, which the present indexes do not. Further we beg to urge that similar subject-matter indexes be formed of all inventions and processes comprised in the very numerous indexes and tables of contents of the scientific books contained in the excellent scientific and technical library of the Patent Office; so that any person using due diligence might easily learn with tolerable certainty whether an invention were new or old, which is not now the case.

We beg to append a sample page of such two subject-matter indexes as we would submit are urgently required. It is almost superfluous to mention that there are now several hundred thousands of pounds accumulated surplus, and an annual surplus of about sixty thousand pounds, contributed by the very class of persons who would benefit by such improved indexes.

L. L. DILLWYN, M.P.
RICHARD BAGGALLAY, M.P.
CHARLES FOX, Mem. Inst. C.E.
CHARLES HUTTON GREGORY, President Inst. C.E.
EDWARD WOODS, Mem. Inst. C.E.
C. WILLIAM SIEMENS, Mem. Inst. C.E., F.R.S.
ROBERT MALLET, Mem. Inst. C.E., F.R.S.
FREDERICK J. BRAMWELL, Mem. Inst. C.E. Council.
EDWARD A. COWPER, Mem. Inst. C.E.

20th March, 1868.

(*Copy of Reply of the Master of the Rolls to Mr. Dillwyn.*)

Rolls, 31st March, 1868.

Sir,

I transmitted to the Lord Chancellor the Memorial presented to me on the 20th March instant by yourself and the gentlemen who accompanied you, relative to the present state of the Patent Office, together with my views on the subject; and we have since considered the matter in consultation together.

The result of this is that we are prepared to recommend to Her Majesty's Government that three gentlemen should be appointed to act as Commissioners of Patents together with the Lord Chancellor and the Master of the Rolls for the time being: one to represent Mechanical Science, another to represent Chemical Science, and a third to represent the subjects more usually and more especially comprised in the term Natural Philosophy. We should propose that the gentlemen to be recommended to Her Majesty for this purpose should be, as regards the first, from gentlemen to be nominated by the Society of Mechanical Engineers; as regards the second, from gentlemen to be nominated by the Chemical Society; and as regards the third, from gentlemen to be nominated by the Council of the Royal Society. But we are not prepared to recommend that any salary should be attached to the services of these gentlemen. We trust and believe that gentlemen fully competent for the purpose may be found, who have sufficient leisure, and who, from their love of science and their desire to disseminate more widely the discoveries made in these branches of science, would be willing to give their services without remuneration, and to superintend the general management of the Patent Office, to see that the Indexes and Abstracts of the Specifications are made accurate and complete, and to redress the other defects complained of in your memorial: acting in all these respects in conjunction with the Lord Chancellor and the Master of the Rolls, to whom they would refer whenever the occasion might require it.

I think it however desirable to repeat that, on fully considering e subject, both the Lord Chancellor and myself have arrived at the nclusion that it would be inexpedient to create either one or more laried officers for this purpose; and to say that we should both, if plied to, recommend Her Majesty's Government not to accedo to at part of the views of the gentlemen who composed the deputation, hich had relation to the creation of paid officers.

ROMILLY.

L. L. Dillwyn, Esq., M.P.

The following gentlemen were accordingly nominated by the eeting for the above purpose:—

Mr. Charles Edwards Amos, ...	London.
Mr. Robert Charles May, ...	London.

The following paper was then read:—

ON THE ALLEN ENGINE AND GOVERNOR.

By Mr. CHARLES T. PORTER, of Manchester.

The objects to be aimed at in carrying out expansion in a steam engine, so as to effect the greatest economy, may be stated to be:—that the full boiler-pressure should be carried into the cylinder at the commencement of the stroke, and maintained up to the point of cut-off;—that the cut-off should be sharp, without reduction of the steam pressure by wire-drawing;—and that the exhaust should be invariable, allowing the steam pressure to act to the end of the stroke with all degrees of expansion, and discharging the steam with the least loss from back pressure during the return stroke.

The attainment of these objects has generally been considered practicable only by means of some kind of liberating valve-gear, in which the valve is released from the gear when wide open, and is closed suddenly by a spring or by the action of gravity; so as to avoid the reduction of pressure by wire-drawing, which ordinarily takes place through the gradual closing of the steam port by a slide-valve worked with a continuous motion. Many ingenious constructions of liberating valve-gear have been invented for effecting this object, more particularly in America, where the subject has received great attention; and amongst them may be specially mentioned the Corliss engine now introduced into this country, which has been found to accomplish the desired end very successfully.

In the Allen Engine however, forming the subject of the present paper, the preceding requirements are met by a direct continuous action of the slide-valves; which gives a sharp cut-off to the steam admitted at full boiler-pressure, and a high range of expansion, together with a very free exhaust. At the same time this arrangement obviates the objection attending the principle of a liberating valve-gear, namely that the speed at which the engine can be worked is limited by the circumstance of the valve having to be disconnected from the driving gear and connected again at each stroke of the engine. The Allen engine admits of being worked at a very high speed, much higher than is usual in stationary engines; and it maintains complete steadiness of motion at this high speed, combined with a great uniformity in the driving power throughout each revolution, although the steam is admitted at an unusually high pressure at the commencement of the stroke.

The engine is represented in Figs. 1 and 2, Plate 9, which show a side elevation and plan of an engine with cylinder of 12 inches diameter and 24 inches stroke. This engine has been running some months at the works of the Whitworth Co., Manchester, at a constant speed of 200 revolutions per minute or 800 feet per minute speed of piston, driving a considerable portion of the machinery in the works; and a similar engine was worked at the late Paris Exhibition, running at the same speed. The engine is horizontal, fixed upon a bed-plate, and working an air-pump direct from the piston-rod, which is prolonged through the outer end of the cylinder. The slide-valves are worked by a link motion, which is controlled entirely by the governor, giving a variable degree of expansion according to the amount of work to be done by the engine; but the steam is always admitted to the cylinder at full boiler-pressure, without passing through a throttle-valve.

Valves and Valve Motion.—The steam slide-valves are shown in the longitudinal and transverse sections of the cylinder, Figs. 3 and 4, Plates 10 and 11. The steam valves are independent of the exhaust valves, and two separate valves are employed, one for each port. The two steam valves E E are driven with separate motions, independent of each other, so as to effect a sharp cut-off at each end of the cylinder by the rapid motion of each valve at the point of closing the port; the motion of one valve being rapidly accelerated at the point of cut-off, at the same time that the other valve is greatly retarded. Each steam valve consists merely of an open rectangular frame sliding between two parallel faces, which are fixed, so that the valve is in equilibrium and its motion is not affected by the pressure of the steam. The outer face F, against which the back of the valve slides, is a rigid plate bridging across the port and fixed down solid to the port face; and it is adjusted so as to allow the valve to slide freely, but with so good a fit as to be steam-tight. The travel of the valve in opening extends beyond the two faces, so as to admit the steam to the port at four places simultaneously, as shown in the separate diagrams, Figs. 13 and 14, Plate 15, in which the length of the valve-rods and the distance between the valves are shortened for convenience in the diagram. In Fig. 13 the steam is shut off from the nearer port; and in Fig. 14 the further steam valve is shown at the point of opening the port, just previous to the commencement of the stroke, the crank being at that moment in the position shown by the dotted line.

In order to maintain the proper working of these valves, the back plate F, Figs. 3 and 4, is made very rigid, so as to prevent any yielding under the pressure of the steam; and the entire plate with its side supports being surrounded by the steam is consequently exposed to the same expansion as the slide-valves. In order to provide the means of adjustment in case of any wear, a packing strip is inserted on each side between the back plate and its side supports; so that by reducing the thickness of these packing strips the two faces can be readily let together at any time to fit the slide-valve. The wear is found however to be so exceedingly slight, on account of the absence of pressure on the rubbing surfaces, that there is no probability of any adjustment being required oftener than once a year.

The exhaust valves G G are also two separate valves, as shown in Figs. 3 and 4, and in the diagram, Fig. 15; but they move together and are driven by the same valve-rod. These slide-valves are of the ordinary form, and work in separate chambers, between the steam valves and the cylinder; they travel beyond the port face, so as to open for the exhaust at the two edges simultaneously. As the steam valves however open at four places simultaneously, the exhaust valves are made of nearly double the width, as shown in Figs. 4 and 6, in order to give a corresponding area of opening; and the extent of their motion is such as to give an area of opening for release of the steam more than double the largest area for admission. These valves work in equilibrium through most of their stroke.

Although there are thus four separate valves for the steam and exhaust, the motion of all of them is obtained from a single eccentric, which is fixed on the crank shaft in the same position as the crank and without any lead, as shown in the diagram, Fig. 16, Plate 16. The eccentric is shown in Figs. 10 to 12, Plate 14, and has a curved slot in one side of the strap, which acts as the expansion link; and it is guided in its motion by being connected to the upper end of the vibrating lever H centred below. Two valve-rods, I and J, are connected to the same slide-block in the link, and attached at the other end to two separate bell-crank levers upon intermediate rocking shafts, as shown in the diagrams, Figs. 13 and 14. One of these rocking shafts is made tubular, with the second running through it, as shown at K in Figs. 11 and 12, so that the two shafts work independently of each other. The second arms of the two bell-crank levers are connected respectively to the two steam valves, Figs. 13 and 14. The slide-block in the expansion link is carried by two side links from the arm of the governor, as shown in Fig. 1, so that its position is regulated entirely by the governor, the block being lowered so as to cut off the steam earlier whenever the governor balls begin to fly out in consequence of any increase of velocity.

The motion of the exhaust valves is invariable, and they are connected direct to a point L, Figs. 10 and 12, beyond the outer end of the link slot. A greater travel is thereby given to the exhaust valves, as shown in Fig. 15, than the greatest travel of the steam valves; and this motion is continued the same during every change of expansion produced by shifting the slide-block from which the steam valves are moved, so that the exhaust continues equally free with every degree of expansion. The point of connection to the link is so placed as to give the required lead to the exhaust valves, and is arranged beforehand to suit the intended speed of piston. The exhaust valves are driven through an intermediate rocking shaft M, Fig. 12, for reversing the motion obtained from the eccentric; and a pair of valve spindles are used, one at each edge of the two valves, as shown in Figs. 4 and 6, and working within the intermediate exhaust port, Fig. 3. The spindles are guided at each end, and each valve is connected to them by two studs fixed in the valve, which fit into slots in the spindles, working clear within the opening of the ports, Figs. 3, 4, and 15. In the case of the steam valves, as the two valves have independent motions, the spindle for driving the further valve passes free through a short tube in the lower side of the nearer valve, Fig. 4; the two spindles are made to clear each other by the valves being placed out of line with each other, as shown in the elevation of the steam port faces, Fig. 5; the spindles are kept central in each of the valves.

All the valves are readily accessible by simply removing the nuts of the steam-chest cover N, Figs. 3 and 4, as the steam-chest is not cast solid upon the cylinder, but is a separate rectangular frame O O, fitted down with a scraped joint on both faces, and secured by the same through-bolts that fix the cover N. This construction has the important practical advantage that the steam-chest can be entirely removed, and all the port faces can be readily got at like plain outside surfaces.

In this valve motion the proportion between the throw of the eccentric and the length of eccentric-rod, or the distance from the centre of the eccentric to the centre of the link, is made the same as the proportion between the main crank and the connecting-rod, which in this engine is 1 to 6, or the length of connecting-rod is 3 times the stroke. Consequently as the eccentric is set exactly to correspond in position with the crank, the angular vibration of the one compensates for that of the other, and an exactly correct valve-motion is obtained, giving the same results for each end of the cylinder. A considerable difference often exists in the indicator figures taken from the opposite ends of a cylinder, in consequence of the discrepancy between the motions of the connecting-rod and the eccentric-rod; and the difference in speed of piston during the first 1° of rotation of the crank at the extreme opposite ends of the stroke amounts to 28 per cent. of the higher speed when the connecting-rod is 6 times the crank, 33 per cent. when 5 times, and 40 per cent. when 4 times the crank.

1 such cases therefore the point of cut-off is not the same in the vo strokes of the piston; but in the present engine the two rokes are identical throughout, in consequence of the eccentric and nnecting-rods having exactly parallel and simultaneous motions.

The connection of the expansion-link to the steam valves by the termediate bell-crank levers introduces in effect a toggle-joint ovement, which has the important advantage of allowing the length the valves to be reduced very considerably, because more than half the lap or useless motion of the valves after having covered the ports dispensed with by their motion being greatly retarded at that time; hilst the opening for steam admission is correspondingly increased the motion of the valves being accelerated at the opposite tremity of their travel. This variation in the motion is shown the diagram of the link motion in Fig. 16, and also in Figs. 13 and 1, together with the varying angular motion of the bell-crank levers 1 the rocking shaft, the reference letters indicating corresponding ositions throughout. The result is seen to be a very great range variation in the motion of the valves, giving on the one hand a ider steam opening and a sharp cut-off with high degrees of pansion, and on the other hand a very slow motion of the valve uring the time that it is simply retaining the port closed. The hole action is obtained with a continuous and perfectly smooth otion throughout.

In the adjustment of the centres of the link motion, the centre of e supporting lever H, Fig. 12, is slightly lowered, so that its upper nd vibrates entirely below the centre line, as shown in Fig. 16, 1 order thereby to equalise the extent of tipping of the link at the vo extremities of its vibration. This gives a slightly increased lead the steam-valve opening at the further end of the cylinder, where e motion of the piston is the more rapid on account of the smaller rc of rotation of the crank; but the point of cut-off of the valves is xactly the same at the opposite ends of the cylinder for each degree expansion, and the point of cut-off can be varied from 4-10ths of e stroke to the very commencement of the stroke.

Indicator diagrams are shown in Fig. 18, Plate 18, taken from is engine, at the speed of 200 revolutions per minute or 800 feet per minute speed of piston; and those in Figs. 19 and 20, Plates 19 and 20, are taken from two larger engines with 18 and 20 inch cylinders working at the speed of 600 feet per minute. This speed of 600 feet per minute is the one that has been adopted in practice for these engines; but the continued successful working of those running at 800 feet per minute shows the higher speed to be quite practicable. The indicator diagrams in Fig. 19 are taken from an engine at Messrs. Pooley's Cotton Mill, Manchester, having a cylinder 18 by 30 inches, and working at 120 revolutions per minute; those in Fig. 20 are from an engine at Messrs. Evan Leigh's works, Manchester, with 20 by 36 inch cylinder, and working at 100 revolutions per minute. In Fig. 19 are shown the effects of wet steam in destroying the sharpness of cut-off, as the boiler was sending over a great deal of water with the steam; and in Fig. 20 a sharp cut-off is shown, as the engine was working with dry steam. The vacuum shown in Fig. 20 is deficient, because the condenser was not in good order. In Fig. 19 the lower straight dotted line A shows the vacuum in the condenser, and the upper straight dotted line B the vacuum in the exhaust chamber at the time of taking the dotted indicator diagram.

The valve motion shown in the drawings is arranged for an engine running always in one direction, as in the case of driving shop machinery; but when a reversing action is required, the expansion-link slot is simply prolonged to an equal distance below the centre line, and exactly similar actions are then obtained in the opposite direction, in consequence of the position of the eccentric being exactly in correspondence with that of the crank.

For the purpose of obtaining the full benefit of expansion, it is requisite, in addition to having the full boiler-pressure in the cylinder and providing a sharp cut-off, that superheated steam should be used, in order not only to prevent water from being carried over into the cylinder with the steam, but also to prevent any loss arising from the freshly admitted steam becoming condensed in the cylinder by contact with the cylinder surface which has been cooled in the previous expansion. About 50° Fahr. of superheating is found desirable; and this proves a more efficient mode than steam-

:ketting, because the superheated steam on admission into the linder supplies heat to the very surfaces that have been cooled exposure to the low-pressure expanded steam.

Speed of Piston.—One of the objects aimed at in this engine to work at speeds considerably higher than those ordinarily ed in any but locomotive engines. For the following reasons it is nsidered that the speed of piston should not be less than 600 feet r minute; but these engines have been worked continuously the higher speed of 800 feet per minute with complete success, d it is believed that still higher speeds may in some cases be ployed with advantage. The valves and the whole of the working rts are so well adapted to maintain a high speed, that the actical objections which ordinarily limit the speed of piston to ver rates do not apply in the case of the present engine.

The principal object in adopting the high speed of piston is to tain a sufficient reciprocating force in the moving parts for lancing the initial force of the steam upon the piston when admitted full boiler-pressure at the commencement of the stroke, so as to ieve the crank from strain on passing the centres; and also to ualise more fully the driving force upon the crank during the tire stroke. At the commencement of each stroke, an accelerating ce is required sufficient to put in motion the mass of the ciprocating parts at the velocity at which the piston moves from a te of rest; and the speed of piston is adjusted so as to make this quired force as great as the actual full force of the steam upon the ton when admitted at the boiler pressure, so that the two forces in equilibrium at that point and the crank pin is thereby relieved m strain when passing the centre. This accelerating force imparted the piston at the commencement of the stroke is given out again ring the retardation of the piston in the latter half of the stroke, d thus compensates for the diminishing driving force of the panding steam, and acts to equalise the driving power upon the nk. A similar action takes place in all engines, but at the speeds piston ordinarily employed its extent is too small to produce any terial effect; and it is only with a high speed that the effect becomes important, since the force required to put in motion or to stop the reciprocating parts increases as the square of their velocity of motion. Where a high speed is combined, as in this engine, with an unusual weight of the reciprocating parts and a short stroke, the inertia of these parts acts as a powerful reciprocating flywheel to equalise the driving power of the engine throughout the revolution of the crank.

In the present engine the weight of the reciprocating parts is 470 lbs., the cylinder 12 inches diameter by 24 inches stroke, and the number of revolutions 200 per minute, or one revolution in 0·3 second. Taking the motion of the piston in the first 1° of revolution of the crank at the commencement of the stroke, the extent of motion will be the versed-sine of an angle of 1° with a radius of 1 foot, or 0·000152 foot in the time of $\frac{1}{360}$ of 0·3 second, or $\frac{1}{1200}$ second; which is equivalent, as regards the accelerating force required to produce it, to a motion of 219 feet in one second, the space passed through under a uniform accelerating force being in proportion to the square of the time. This motion of 219 feet in one second is 13·7 times the effect of gravity (16·08 feet in one second); and consequently the force required to impart the velocity amounts to 13·7 times the weight of the reciprocating parts (470 lbs.), making a total force of 6439 lbs., which is equal to a pressure of 57 lbs. per square inch upon the area of the 12 inch piston. It follows therefore that the steam at the full pressure of 57 lbs. may be admitted suddenly to the cylinder at the commencement of the stroke, without causing any strain upon the crank pin; and indeed this full pressure is absolutely required upon the piston at that moment, in order to prevent a strain in the opposite direction upon the crank pin from the inertia of the reciprocating parts.

This principle is carried out in the regular working of the engine shown in the drawings, which has been running constantly for some months at the Whitworth Co.'s works with the speed of piston of 800 feet per minute; it is worked in direct communication with a boiler of 60 lbs. pressure, without any intermediate throttle-valve to reduce the pressure of the steam before entering the cylinder. The indicator figures given in Figs. 18, 19, and 20, show an excessive variation of pressure upon the piston throughout the stroke, ranging rom 70 lbs. down to 10 lbs. per inch total pressure above a perfect acuum; but in order to ascertain the effective driving power upon he crank, the whole amount of the pressure due to the inertia f the reciprocating parts has to be deducted at the beginning f the stroke, and the same amount has to be added to the indicator igure at the end of the stroke, both amounts being gradually educed to nothing at the middle of the stroke. This correction cts directly to compensate for the inequality of the indicator figure, nd the effective driving power throughout the stroke is thereby qualised to a remarkable extent. In the diagram, Fig. 17, Plate 17, he pressure produced upon the crank pin by the inertia of the eciprocating parts during the acceleration and retardation of the iston in each half of the stroke is represented by the dotted ine A A, the amount of the pressure at the beginning of the troke being represented by the distance A C from the horizontal ase line C C; this diminishes to nothing at the middle of the troke, and becomes an equal amount of pressure A C at the end f the stroke, but in the opposite direction. The rate of change is niform, during equal spaces passed through by the piston, and is epresented by the straight dotted line A A, if the varying angular otion of the connecting-rod be neglected; but when this is taken nto account, the result is modified practically to the slightly curved ne B B.

For carrying out a high degree of expansion a high speed of iston is essentially requisite, in order that a sufficient amount of qualising effect may be obtained from the inertia of the reciprocating arts, to compensate for the extreme variation in steam pressure hich is consequent upon an early cut-off. Indeed in consideration f smoothness of running, the engine should be run so fast that the riving force produced by the highest pressure of steam cannot xceed the inertia of the reciprocating parts; and then a knock pon the centres becomes as impossible as it would be in a evolving sling.

A high speed of piston is also advantageous on account of the eduction in size of engine required to supply a given amount of power, whereby an important saving in space and cost is effected; and also on account of the increased uniformity of motion obtained with the higher speed. Taking the case of a single engine in place of a pair of coupled engines running at half the speed, the strokes are as frequent as those of the pair of engines, while the inequalities in the rotative force are not much larger, owing to the great equalising effects of the inertia of the reciprocating parts at the high speed. Moreover as the regulating power of the flywheel increases in proportion to the square of the number of revolutions in a given time, the same wheel has four times the regulating power when run at double the speed.

The practical objections generally considered to apply to a high speed of working are, increased wear and tear, risk of hot bearings, cutting of the cylinders and pistons, and shaking loose in the fixings. But instead of any difficulties of this kind having been experienced, this engine runs smoothly and quietly, without tremor and without warming in the bearings, running continuously without requiring attention, and showing exceedingly slight wear in the cylinders, valves, and bearings. This result has been attained simply by good mechanical construction and workmanship; avoiding any unbalanced action, overhanging strains, insufficient stiffness of framing, inadequate bearing surface, or want of truth in workmanship. Unless all these conditions are carefully attended to, high speed is certainly not practicable; but when they are thoroughly carried out, no difficulty is experienced in working at any desired speed.

In the previous consideration of the effect produced by the inertia of the reciprocating parts, this has been taken as the same at each end of the stroke; but in reality a considerable difference is caused by the angular motion of the connecting-rod at the two ends of the stroke; and the actual motion of the piston during the first 1° of rotation of the crank, instead of being 0·000152 foot at each end, is 0·000178 at the outer end of the stroke, and only 0·000127 at the inner end. Consequently, from this approximate mode of calculating by the difference in motion of the piston during the first degree of rotation from each end of the stroke, the pressure on the piston required to balance the inertia, instead of being 57 lbs. per inch at th ends as named before, would be 66 lbs. at the outer end and ½ lbs. at the inner end. In the case of inverted vertical engines, the eight of the reciprocating parts acting vertically tends to equalise ese amounts, by being added at the outer or upper end and ducted at the lower end. For this reason, and on account of the ore correct support of the cylinder and the absence of overhanging rains, that form of engine seems preferable for the highest speeds.

Condenser and Air-Pump.—In the arrangement of the condenser d air-pump the object has been to meet the difficulty of combining e advantage of a simple direct-acting air-pump with the very usually high speed of working, 200 revolutions per minute. is has been effected with complete success by the construction opted; a vacuum of 27 inches of mercury is maintained with great eadiness, and the air-pump works quite quietly and without noise at e full speed, and keeps thoroughly in order without requiring y attention.

The air-pump, as shown in Figs. 1 and 2 and in the transverse ction, Fig. 7, Plate 12, is a nearly cubical box filled with water, th a plunger working through a stuffing-box in the lower part; the unger is attached to the piston-rod and forms a continuation of it. e end of the plunger is made of a parabolic shape, as shown Fig. 1, for displacing the water easily; and the plunger works tirely immersed in the water, simply displacing its own bulk of ater at each stroke.

The inlet and outlet valves are all placed in the top plate of the x in two parallel rows, three inlet valves in one row and three tlet valves in the other, as shown in the plan, Fig. 2. They are dia-rubber disc-valves with 8 inches diameter of opening, Fig. 7, d slide parallel upon their centre spindles without any bending of e india-rubber, being fitted with a metal plate and a long centre sh to guide the discs steadily in opening and closing, and to event any wear upon the edge of the india-rubber. The lift of the lves is about ½ inch, and in order to obtain a quick action in sing they are closed by spiral springs, which load the valves the extent of ¼ lb. per square inch. These springs are found necessary upon the outlet valves as well as the inlet, in consequence of the quickness of the action required to close them 200 times per minute; and it was found that even at the speed of 120 times per minute there was a loss of 1 lb. per inch in the vacuum when the springs were not used, from the valves not closing promptly enough.

The condenser forms one half of the chamber above the air-pump, and the hot-well the other half, as shown in Fig. 7. The injection is introduced by a single opening in the centre of the condenser, with the full area of the pipe, in order to avoid any risk of the injection opening getting contracted by accumulation of deposit in a spreader or rose; and it has been found that no perceptible difference is caused by this arrangement in the vacuum obtained with the injection. In consequence of the position of the valves in the top plate of the air-pump chamber, the air entering from the condenser does not pass through the water, but simply passes over the surface of the water from the inlet to the outlet valves; and the water rising up to the outlet valves at each stroke ensures the discharge of the whole of the air. As no air gets to the lower portion of the air-pump chamber, the plunger works always in solid water, avoiding any churning action of mixed water and air; and indeed the effective piston of the air-pump may be considered to be, not the plunger, but the surface of the body of water that always remains in the air-pump chamber, which rises and falls at each stroke of the pump through a distance of less than one inch. The working velocity of the air-pump piston is therefore reduced in effect to only about 30 feet per minute, instead of 800 feet per minute the actual velocity of the plunger.

For the purpose of facilitating the passage of the air from the inlet to the outlet valves, the former are set at a small inclination below the horizontal position, as shown in Fig. 7, this idea having been suggested by a marine engine of Messrs. Maudslay and Field. The arrangement and position of this condenser and air-pump are very convenient for access to all the parts, the whole being above ground and at the level of the engine. It is held steady in its position by a connecting tie to the frame below and by the fixing of the exhaust-pipe above; and it serves as an additional guide for the smooth working of the piston-rod beyond the cylinder. The weight of the plunger moving at the full velocity of the piston serves also as an important addition to the compensating action of the inertia at the commencement and end of each stroke.

Governor.—The expansion gear of the engine is regulated entirely by the self-acting movement of the governor, Figs. 1 and 2; and for carrying this plan out satisfactorily it is essential to have a governor that is extremely sensitive to any change of velocity, and acts with great promptness upon the expansion gear, with power sufficient to shift it instantly to the full extent required. The governor used for the purpose has been designed by the writer as a modification of the ordinary Watt centrifugal governor, with the view of increasing its sensitiveness and quickness of action, and adding to the power available for overcoming the resistance of the valve motion. This resistance is however reduced to a very small amount in the present engine, on account of the valves being in equilibrium.

The governor is shown in Figs. 8 and 9, Plate 13, and consists of two revolving balls of small size, but moving at a high velocity, which pull up a heavy central weight, when they rise in consequence of an increased velocity of revolution; the balls are only about 2 to 3 lbs. weight, but the central weight is from 50 to 300 lbs. according to the size of the governor. The connection of the radius rods to the centre spindle is made with forked ends having considerable width of fork, as shown in Fig. 8, and fitting upon a pin which passes through the axis of rotation, Fig. 9. The friction which opposes the rise and fall of the balls is thus reduced, by the pressure upon the pin at the joints of the rods being diminished in consequence of their increased leverage; and the sensitiveness of the governor is thereby increased, its friction being much less than that of the ordinary governor.

With the very heavy revolving balls employed in the ordinary construction of governor, a large amount of resistance is opposed by their inertia when they are required to act by rising or falling, on the occurrence of a change in the velocity of revolution. A serious pressure is also caused on the joints of the radius rods when the inertia of heavy balls of 1 cwt. each has to be overcome in order to accelerate their motion; and the friction caused by this pressure on the joints prevents the change of position of the balls, until a sufficient increase of velocity has occurred to accumulate force enough for overcoming this resistance. The engine is thus allowed to vary considerably in speed; and the balls of the governor are then liable to fly out too far, causing too great an action for properly regulating the speed of the engine. In the present governor the revolving balls being of very small weight offer little resistance by their inertia to any change, and they rise or fall instantly when any change takes place in the speed of revolution of the engine. Their centrifugal force is made up to that of the ordinary heavy balls by their increased velocity of revolution, the centrifugal force increasing as the square of the velocity; and they are driven at a speed of from 320 to 400 revolutions per minute.

This governor is liable to the same objection in principle as the ordinary Watt centrifugal governor, namely that it can only regulate the engine for a variation of load by maintaining a corresponding change of velocity in the engine; but in this governor the action is so much more sensitive and extended than in the ordinary governor that this objection is practically got rid of. It is found to regulate the speed of the engine with certainty within the range of 2 per cent. variation of speed, with the greatest extent of variation that can occur in the load; and a variation in speed of 5 per cent. would carry the governor through its entire range of action, and shut off the steam from the engine. In practice the steam stop-valve is always set wide open, and the engine runs under all circumstances with complete steadiness and uniformity of motion, without requiring any attention; and the most sudden and extreme changes of load do not affect its motion perceptibly.

Special Construction.—In practically carrying out the high speed of working that has been adopted in this engine, special attention has been required to ensure the rigidity of both the stationary and the moving parts, to balance the forces of the moving parts, and to obtain a large extent of hardened rubbing surface, with perfect truth of form in the wearing parts. When due attention is paid to these points it is found that there is no practical difficulty attending the employment of the high speed; and the objections ordinarily felt to it arise really from imperfections of construction in these respects.

For the purpose of obtaining the required rigidity in this engine, the base-plate is made a hollow casting of great stiffness and unusual depth, and the centre line of strain of the engine is brought down very near to its surface. The cylinder is bolted to the end of the base-plate, and is held all round the circumference of its inner end; but it is left free from the base-plate throughout its entire length. The object of this arrangement is to leave the cylinder free to expand and contract, without the tendency to distortion which arises when the cylinder is fixed down throughout one side to a cold base-plate, whilst kept heated along the other side by the steam-chest. The cylinder thus preserves its parallelism when at work, so that a deep and well fitted piston can be used; the piston employed is a plain hollow block, turned a close fit to the cylinder, and fitted with two Ramsbottom rings. The result is that, instead of the injurious wear often experienced in horizontal cylinders working at the lower speeds, the cylinders of these engines are found to be always in a polished and greasy condition, and their wear is inappreciable.

In all the working parts of the engine the bearings are made both unusually long and large in diameter, and by this means the pressure per square inch on the bearing surfaces is diminished, so that a thicker film of oil is maintained between them, reducing the coefficient of friction. The smoothness of running is thus increased also, by avoiding the injurious effects that arise from the bearings not having sufficient rigidity to resist flexure or torsion. In all the bearings special care is taken to obtain perfect truth of form, which is a point of great practical importance; and if properly formed and hardened these bearings should not be subjected to wear at all. The difference in working is remarkable between a true cylindrical form and such an approximation to it as can be produced by turning in a good lathe. When a truly cylindrical journal or pin has been produced by the operation of grinding with a traversing wheel, in dead centres which have themselves been ground to true cones, such a cylinder, if it has sufficient surface and rigidity and is fitted in proper bearings, floats in an oil bath, being separated from the bearings at every point by a film of oil of exactly uniform thickness; this film cannot anywhere be broken, and having scarcely any disposition to work out will last without renewal for a great length of time; and the coefficient of friction under pressure is thereby greatly diminished. This truth of form is really easy of attainment, and if its value were fully appreciated it would certainly be obtained in general practice.

Mr. **Porter** said he had hoped to be able to give the results of a series of comparative trials with one of the Allen engines, as compared with an ordinary engine of good construction and of the same power, working under the same circumstances. It had unfortunately been impracticable however to get these trials carried out yet; but it was intended to proceed with a very thorough set of experiments for this purpose.

Mr. E. A. **Cowper** enquired what were the particulars of the ordinary engine, with which it was proposed to compare the Allen engine in the experiments; whether it was provided with a separate expansion slide-valve, and what was the degree of expansion employed, and also what was the construction of the air-pump, and whether the cylinder had a steam jacket.

Mr. **Porter** replied that the other engine was an ordinary horizontal high-pressure engine with an 18 inch cylinder, which had previously driven the shop for three years at the Whitworth Co.'s works, and it had been fitted with a condenser and air-pump exactly the same as those of the Allen engine; so that the comparison would not be complicated by the degree of condensation or the power required to work the air-pump. The cylinder of the engine had not a steam jacket. The steam was cut off at half stroke, and the slide-valve was an ordinary slide cutting off by the lap, without a separate cut-off slide on the back: the object being to make a comparison between the Allen valve motion with variable expansion regulated by the governor, and the ordinary slide-valve worked by a single eccentric, with the governor acting upon the throttle-valve in the steam pipe.

Mr. E. A. **Cowper** thought that for a satisfactory comparison the ordinary engine should be furnished with a separate expansion valve, as was now the common practice in good engines, and also the cylinder should be provided with a steam jacket.

Mr. C. W. **Siemens** remarked that, as the value of any comparison between the Allen engine and an ordinary engine would depend altogether upon the particular condition of the latter, it would be much better to have the results of the Allen engine stated independently, giving the consumption of steam per horse power of the work done; this would afford the means of comparing the performance generally with that of any other engines. He was much struck with the very complete manner in which the various mechanical details in the construction of the engine had been worked out; and by the plan of carefully adjusting the weight of the reciprocating parts, so that their inertia at the commencement of the stroke should just counterbalance the highest steam pressure, there was no doubt that a very perfect result would be obtained, provided the speed was always maintained at the full rate upon which the calculation of the inertia was based. The main question he thought was whether the original fine adjustment of the working faces, particularly of the cylinder and slide-valves, could be practically maintained in continued work at the high speed at which the engine had to run; for although the wear of these surfaces might be reduced to a very great extent even at such a high speed, by great care in working and by the use of steam perfectly free from priming, yet it was hardly to be expected that these conditions could be constantly ensured in actual working for a length of time. It was therefore desirable to ascertain by actual observation what would be the result of continued working with a full load upon the engine. In the engine exhibited last year in Paris it appeared the bearing surfaces had not been altogether suited for the heavy load for which the power of the engine was calculated; and the results of the trials with that engine had not been so satisfactory as they would have been, if care had been taken to increase the extent of the bearing surfaces in proportion to the load put upon the engine.

The governor described in the paper would he thought certainly be quicker in its action than the ordinary arrangement; and no doubt if an ordinary ball governor were weighted down in a similar manner by a weight or a spring, and had its speed accelerated to the same extent, its quickness of action would be correspondingly increased. The improved governor was in fact a Watt governor revolving at a higher speed; and it was therefore necessarily subject to the defects attending the principle of that governor, namely that at the moment when the engine began to change its speed the governor was without any power to act upon the valve, and it had then to accumulate power itself before it could control the engine. He should have felt some hesitation in going to such a high speed with the revolving ball governor, for fear of rapid wear and tear; but this was a point which would be decided by the results of actual working.

Mr. F. W. Webb concurred in the opinion that the most useful criterion of the economy of the Allen engine would be the actual consumption of fuel per horse power; and from his own experience of high speeds he agreed in thinking there would be a difficulty in maintaining the wearing surfaces of the slide-valves and cylinder, so as to keep them steam-tight in continued working.

Mr. E. Reynolds said he had seen the Allen engine at work at Manchester on several occasions, and he had also seen the ordinary engine that had been mentioned, with which it was proposed to make the comparative trial; and from the results said to be obtained with it he thought the latter might be taken as a very favourable example of an ordinary condensing engine. Simplicity of construction was a very important consideration in an engine for common use; and if an ordinary horizontal condensing engine, with a single slide-valve cutting off at half stroke, without a separate expansion valve, and without superheating the steam, could be made to work with 3 lbs. of coal per horse power per hour, which he understood was the case at the Whitworth Co.'s works, a very high result was attained.

The effect of the inertia of the reciprocating parts was a matter of great practical importance in any high-speed engine; and although the general principle had long been admitted, it did not appear to have been fully understood previously, and at any rate had not been fully acted upon in practice hitherto. In the present instance the effect of that inertia appeared to have been arrived at by a tentative process, by calculating the amounts of acceleration and retardation through each degree of revolution of the crank, and then the forces necessary to produce them. The simple way however to calculate the actual effect produced upon the crank pin by the inertia of the reciprocating parts in a horizontal engine seemed to him to be by supposing the whole weight of the horizontal reciprocating parts to be concentrated at the crank pin; and the centrifugal force due to the revolution of this weight in the circle of the crank being then resolved at any point of the circle into the vertical and horizontal directions, he considered that the horizontal component would represent the actual effect produced upon the crank pin at that point by the inertia attending the horizontal reciprocation of the same weight if accelerated and retarded in precisely the same degree and manner, though having horizontal motion only. In this mode of calculation the line representing the force necessary to produce the acceleration of the reciprocating parts by the crank in the first half of the stroke and their retardation in the latter half, during equal spaces passed through by the piston, would be a straight line corresponding with that described in the paper and shown in the diagram (Fig. 17), for a connecting-rod of infinite length; the maximum effect upon the crank pin being at the commencement and end of the stroke, at the moment when the crank was passing the centre, while the effect of the inertia became nothing at the middle point of the stroke. The effect of taking into account the length of the connecting-rod would be obtained by considering in an exactly similar manner the centrifugal force due to the angular motion of the rod in its arc of vibration, the horizontal component of which at every point of the stroke would have to be added in the outer half of the stroke to that previously ascertained with an infinite length of rod, and deducted in the inner half. At the two extremities of the stroke therefore, the lineal velocity of the crank pin in its circle of revolution and of the connecting-rod end in its arc of vibration being at that moment identical, the amounts of centrifugal force due to the crank and to the connecting-rod would be in the inverse ratio of their lengths; and in the case of a connecting-rod having six times the length of the crank, the centrifugal force due to the connecting-rod would thus cause an addition or deduction of one-sixth upon that due to the crank. The total pressure produced on the crank pin by the inertia of the reciprocating parts would accordingly be seven-sixths at the outer extremity of the stroke and five-sixths at the inner extremity, in comparison with the equal pressure at both ends due to a connecting-rod of infinite length; thus giving a difference of 16⅔ per cent. above and below the mean of the two, which was the same result as that obtained in the paper by a different method of calculation. On account of this difference it was clear that no single counterbalance weight, such as that added upon the driving wheel of a locomotive engine, could accomplish a true balance throughout the whole stroke; the utmost that could be done by such means was to balance the mean inertia, leaving the variation between the two extremities of the stroke without compensation. Although with the proportions and counterweights adopted in most engines at the present time this variation was not so considerable as to be of much importance, he thought it was still worth while to draw attention to the fact, in order to show the futility of attempting an absolutely true balance. This attempt had been made in the "duplex" locomotive engine shown at the International Exhibition in 1862 (see Proceedings Inst. M. E. 1863, page 97), one piston at one end of the stroke being intended to balance the other piston at the opposite end. But even in that case, though the difference in pressure of the wheels upon the rails due to the vertical action of a revolving counterweight in the wheel was avoided, yet the inequality in the inertia in the two halves of the stroke was still left untouched; as was also the vertical pressure of the crossheads against the slide-bars, tending to lift the two sides of the engine alternately: and no nearer approximation to a true balance was really effected than in ordinary engines having counterweights attached to the wheels. In locomotives, in consequence of the variable speed as well as this difficulty in balancing, he thought the best mode of attaining steadiness in running was to keep the pistons and other reciprocating parts as light as possible; but in stationary engines intended to run constantly at a given uniform speed, it was most advantageous, as shown in the paper, that these parts should have a considerable amount of weight, so as to give the amount of inertia calculated to correspond with the standard speed of working.

The importance of bestowing sufficient attention upon the details of an engine appeared to him to be well illustrated by the working of the Allen engine at Messrs. Pooley's cotton mill in Manchester, which he had recently seen at work doing a heavy duty perfectly well, and with complete freedom from any signs of heating or undue strain. In general when it had been attempted to run a horizontal engine continuously at a high speed under a heavy load, the result had been that the bearings became very hot, unless a great deal of play were allowed; and on this account all previous attempts that he was acquainted with of running such engines at a speed anything like 600 feet per minute of the piston had been attended with much trouble and annoyance. At that speed however, and even higher speeds, the Allen engine worked quite comfortably, owing probably in a great measure to the special care taken to provide ample bearing surfaces and to get them up truly cylindrical. Another part of the engine which had been well worked out in the details was the air-pump. There was perhaps nothing strictly new in the plan of air-pump adopted for the Allen engine, as the importance of getting a large extent of surface for the water with small extent of motion had been previously advocated, instead of having the area of the water surface only the same as the area of the piston, as in ordinary air-pumps; nevertheless high-speed air-pumps had always been a difficulty, as shown by the violent oscillations of the vacuum gauge even under the best arrangements previously tried. In the ordinary engine however which he had seen at the Whitworth Co.'s works, fitted with the improved air-pump described in the paper, the vacuum gauge remained remarkably steady with the cock wide open, even when the engine was running at the high speed of 94 revolutions per minute; at that speed there was only a slight pulsation in the gauge, instead of the sudden oscillations which would be exhibited with an ordinary air-pump driven at a considerably lower speed. This result showed that attention to the details was of the highest importance for the efficient working of an engine; and the same remark applied to the plummer blocks for carrying the main driving shaft, which he thought were well arranged for getting over the difficulty often experienced in horizontal engines of avoiding horizontal play without inducing heating of the bearings.

In regard to the improved construction of governor described in the paper, he thought that although an ordinary Watt governor if loaded in the same proportion might theoretically be considered to be equivalent in action, yet in that case the friction on the collars would necessarily be so great as to require a very large power to drive it; whereas by the device of taking so much weight out of the balls themselves, and applying it instead in the shape of a central weight lifted by the toggle-joint, the inertia of the balls was so far reduced that they offered much less resistance to any rise or fall corresponding to a change of speed. A less amount of power would therefore produce a given rise of the light balls in the improved governor, though lifting a weight equal to that of the heavy balls in an ordinary governor. On this account, and considering also the other improvements in the detail of the governor, he could believe that the extreme variation of speed in an engine controlled by this governor would not exceed 2 per cent. Having himself used many of these governors, he had found their increased sensitiveness rendered the speed of the engines remarkably steady; and as a cheap and simple construction of governor, sufficient for all ordinary circumstances, he considered the improved arrangement was a very valuable contrivance.

The Chairman remarked that the consumption which had been mentioned of only 3 lbs. of coal per horse power per hour, by an engine expanding only twice, was a very remarkable result; he had never heard of such a performance before, and would be glad to know whether the statement had been verified.

Mr. E. **Reynolds** said that was stated to be the consumption of the ordinary engine at the Whitworth Co.'s works. It did not follow however that, because the slide-valve cut off at half stroke, the expansion was only twofold; for though the steam was throttled in the steam pipe, it had ample time to accumulate in the steam chest during the latter half of each stroke, after it was cut off from the cylinder; so that the full pressure of steam came upon the piston at the commencement of each stroke, and was very rapidly reduced as the stroke progressed by wire-drawing through the throttle-valve, in consequence of which the resulting indicator diagrams were not very different from those produced by true expansion with a considerably earlier cut-off.

Mr. **Porter** explained that the consumption of 3 lbs. of coal per indicated horse power per hour in the ordinary engine at the Whitworth Co.'s works was exclusive of raising steam at starting in the morning; the temperature of the feed-water, supplied to the boiler during working was below 100° Fahr. This result had been obtained in a week's careful experiment, and he believed its accuracy was unquestionable. The fuel used was the ordinary Lancashire coal, which was so much inferior in heating power to the Welsh, that the consumption of 3 lbs. per indicated horse power would be equivalent to only about 2½ lbs. of good Welsh coal.

Mr. E. A. **Cowper** remarked that he could not approve of the Allen engine, but on the present occasion he did not wish to go into the questions of the high speed of piston or details of the engine, and would only refer to the subject which had been alluded to of the plus and minus pressure exerted on the crank pin by the momentum of the reciprocating parts. When the velocity of the piston was changing from an accelerating to a diminishing velocity in the middle of the stroke, there was no plus or minus pressure on the crank pin; but when the crank had passed the end of the stroke and the velocity of the piston was increasing, there was a minus pressure, that is, a portion of the pressure of the steam on the piston was absorbed in getting up its velocity and was not at that time developed on the crank pin; and then again in the latter portion of the stroke there was a plus pressure or extra pressure on the crank pin over and above the pressure of the steam, from the fact of the crank pin then retarding and changing the velocity of the piston. If the ordinates of this plus and minus pressure were set out to form a diagram, they would give a curve dying away to nothing at about half stroke.

He wished to enquire whether it was intended that, on account of the very high speed of piston in the Allen engine, a small-cylinder engine on that construction should be considered as one of large power.

Mr. L. OLRICK said he had seen the Allen engine at work at the Paris Exhibition, and also the very excellent sectional working model that was shown there, which gave a very clear idea of the valve motion worked from the single eccentric. By the very simple and ingenious arrangement of the bell-crank levers working the two slides, the object was attained of a sharp cut-off, without contracting the port openings by the gradual closing of the valve, as was the case with an ordinary slide-valve driven by an eccentric; and a very free opening was afforded for the admission of the steam, which entered at four distinct places simultaneously; while the entire valve motion was worked by a single eccentric always in gear. In respect to the governor described in the paper, there could be no doubt that the chronometric governor of Mr. Siemens was quicker in action and the nearest approach to absolute perfection; that governor was however rather more complicated in construction, and the ball-governor now described was certainly very simple and sufficiently perfect for most ordinary engines; for although in principle it was a Watt governor and involved therefore the same fundamental defects, these were reduced to a very small actual amount, by the improved construction of the parts and the use of much lighter balls revolving at a much higher speed. By the working of the Allen engine the very high speed of piston mentioned in the paper had now been shown to be practicable, without involving the objections usually experienced hitherto in any attempts to increase the speed of piston considerably; and he thought the successful results now attained were satisfactorily accounted for by the explanation given in the paper, the weight of the reciprocating parts being augmented to such an extent that their inertia entirely absorbed all the initial surplus pressure of the steam on the piston at the beginning of each stroke, thus relieving the crank pin from the usual great strain on the centres, which would otherwise be most dangerous with such quick-working engines. This principle having been so carefully carried out in the proportions adopted in the Allen engine rendered it a race-horse in speed as compared with ordinary engines; and for such an engine the lighter and more sensitive governor of Mr. Porter was excellently adapted. They were also indebted to him for the introduction into this country of the Richards indicator, the lighter and more sensitive construction of which rendered it the only instrument capable of giving a correct diagram from an engine running at a very high speed. The remarkable attention paid to the details in all the parts of the Allen engine might be imitated with great advantage he thought in all other descriptions of machinery, the ordinary turned bearings being only approximately cylindrical, and in reality more or less polygonal; but it was only in conjunction with ample extent of surface and perfectly round bearings that the high speeds of working described in the paper had been so successfully realised.

Mr. H. **Woods** asked if it was intended in the construction of the Allen engine in the future to discontinue the use of the steam jacket.

Mr. J. **Fernie** said he had seen the Allen engine when first shown at the 1862 Exhibition, and also the improved one at the Paris Exhibition and the one working in Manchester, and he had been much pleased with their performance; they were very steady at the great speed at which they ran, and seemed to do the work with remarkable ease. One reason of the smoothness of running was that there was no feed-pump attached to the engine, and the rattling action attendant upon a pump was thereby avoided. The speed of piston, although much higher than was usual in stationary engines, was not more than was general in locomotives; for a locomotive running at 40 to 50 miles an hour had a piston speed of about 600 feet per minute. With the adoption however of this high speed in stationary engines, he suggested that it would be very desirable at the same time to increase the pressure of steam up to 100 or 150 lbs. per square inch, in accordance with the present practice in locomotives; if this were done, and the principles already carried out in the Allen engine were as carefully adhered to with the higher pressure, he thought the results obtained would be still more advantageous. He enquired what was the amount of lead given to the slide-valve, in working with the single eccentric; and also what was the practical advantage afforded by the engine, in respect to the proportion between the power obtained and the space occupied.

Mr. A. Coventry, having had several opportunities of seeing the Allen engine at work in Manchester and in London, considered the most distinctive feature about it was that it took up all the best points of other engines, and combined them in one engine. A quick cut-off was obtained, with a variable expansion regulated by the governor according to the load on the engine; at the same time the exhaust was invariable at all grades of expansion, and very free. It was also deserving of remark that for an engine combining all these advantages it contained the smallest possible number of parts.

Mr. Porter remarked that the piston speed of 800 feet per minute in the Allen engine at the Whitworth Co.'s works was considered exceptional; and the standard speed in calculating the proportions of the engine had been taken at 600 feet per minute. At the same time if a higher speed, even up to 1000 feet per minute, were desired for any special purpose, he should not hesitate to run the engine at that rate, with suitable modifications in the proportions of the parts.

In reference to the heating of one of the bearings in the engine at the Paris Exhibition, as mentioned in the paper, that was not owing to want of sufficient extent of surface, but was altogether an accident arising from an error in the bearing, which caused it to be imperfectly lubricated. The dimensions of the bearings were very large; and the engine at the Whitworth Co.'s works, with the same dimensions, had been working very satisfactorily under a load twice as heavy as that put upon the engine in Paris. With the ample extent of bearing surface that was provided, it had been found that the engine was perfectly safe from heating, so long as uniform lubrication was ensured. On the engine at Manchester all risk of imperfect lubrication was prevented by the employment of a continuous mechanical lubricator, consisting of a brass cup fitted with a cock having a solid plug, in one side of which was drilled a hole large enough to hold a couple of drops of oil, so that at each revolution of the plug that quantity of oil was supplied to the crank pin; the plug was caused to revolve by means of a worm and wheel, actuated by a small cam let into the circumference of the crank-pin collar. In lubricating with the ordinary cotton wick as a syphon, it occasionally happened that the lubrication failed for a length of time without the defect being observed; but the mechanical lubricator had been found to remove that difficulty altogether.

The lead of the valves was necessarily considerable in running at a high speed, in order to afford a sufficient area of inlet for completely filling the port and clearance space at the commencement of each stroke; and in the original setting of the valves the lead was adjusted with reference to the indicator diagram, until a figure was obtained with a sufficiently square corner at the beginning of the stroke. The amount of lead thus arrived at was such that the steam could not be entirely shut off by the governor, when the work was thrown off the engine; but when the whole load was thrown off excepting only the main line of shafting driven by the engine, the admission of steam was so far reduced by the governor that no acceleration of speed took place in the engine.

For taking up the wear of the slide-valves the requisite means of accurate adjustment was provided in the manner described in the paper, by the insertion of packing strips underneath the supports of the cover-plate on the back of the valves; so that the rubbing faces could be let together at any time to the exact extent required, by simply reducing the thickness of these packing strips. The form of piston to be used was quite immaterial; the piston which he had employed was packed with two Ramsbottom rings, as shown in the drawing, and had been found quite satisfactory.

The governor controlling the Allen engine was absolutely the same in principle as the original Watt governor; but the object had been to obtain a nearer approach in practice to the degree of perfection of which that principle was capable. This was effected by reducing as far as possible the severe friction upon the joints, which exerted so great a retarding force upon the action of the ordinary governor; and a further step was the substitution of the central heavy weight, instead of putting the whole amount of weight into the revolving balls.

It was the consideration of the inertia of the reciprocating parts which he thought constituted the most important point in the construction of the Allen engine; and in the case of the engine at the Whitworth Co.'s works this consideration had justified the adoption of a mean initial steam pressure as high as 57 lbs. per square inch; but were it not for the compensating effect of the inertia of a heavy piston, it would be impossible for the crank pin to stand anything like such a pressure in an engine of that size. By the exact balancing of the initial pressure of steam and the inertia of the reciprocating parts an increased smoothness in running was obtained, and a gliding motion in passing the centres, instead of having a concussion upon the crank pin at these points.

The air-pump did not contain any entirely new features, but was simply a combination of all the best points in previous air-pumps, and he thought it was a very satisfactory solution of the question of working an air-pump in an engine running at a high speed. The vacuum constantly maintained at the speed of 94 revolutions per minute was 27½ inches of mercury and often 28 inches; and even at 200 revolutions per minute the average vacuum was 26 inches. No trouble whatever had been experienced with the air-pump in regularly working at those high speeds.

The use of a steam-jacket he had been led to abandon in the case of small engines; for although it was unquestionably advantageous wherever there was abundant communication with the boiler, so as to get the full heat of the boiler steam in the jacket and allow the condensed water to drain back freely, yet in small engines there was much difficulty in ensuring these conditions being carried out. It frequently happened indeed that, owing to the accumulation of water in the steam-jacket, the temperature surrounding the cylinder was considerably lower than that at which the steam entered the cylinder; and under such circumstances the jacket was of course an injury rather than a benefit. In expanding to a very great extent, such as cutting off the steam at 1-10th of the stroke, it was certainly impossible to work with advantage unless the cylinder was jacketted; but on the other hand he did not think it desirable in practice to cut off the steam so early as 1-10th, and he considered a cut off at 1-6th or 1-5th was the earliest that was advisable. Although expansion had great advantages in economy of fuel, it might be overdone, if the limits assigned by other considerations were not attended to.

The degree of accuracy of work required in an engine running at the high speeds named in the paper was nothing more than the best makers of engines and machinery were now thoroughly accustomed to; what would be considered reasonably good work for other similar purposes would do very well for a high-speed engine; but of course any errors arising from inferior work were sooner detected by the high speed, and their evil effects aggravated. In the case of the Allen engine at the Whitworth Co.'s works, the result of the large extent of the wearing surfaces and the excellence of the work had been that, after running constantly for several months, there was absolutely no wear about it at all: the cylinder and slide-valve faces were perfectly smooth, and the guide bars still showed the original marks of the scraping tool.

The commercial benefits attending the Allen engine were not so important a subject for consideration, he thought, as its mechanical advantages; and a reasonably high speed had a great many advantages for stationary engines besides the saving of space and the economy in first cost. In the present instance, with the high speed now employed, the engine had only a single cylinder instead of two cylinders coupled at right angles, and yet gave the same uniformity of motion; it was also a horizontal engine instead of a beam engine, and a simple engine instead of a compound one.

The pressure of steam employed in the Allen engine at the Whitworth Co.'s works, namely 57 lbs. per square inch, although higher than hitherto commonly adopted in condensing stationary engines, was by no means so high as he thought might with advantage be used; and he agreed in considering that the higher the pressure, the better would be the results obtained from the engine. The proportions of the several parts would of course have to be modified for an increase of pressure beyond certain limits; and the engines could be constructed to work at any steam pressure that might be desired. The number of separate parts contained in the engine was on the whole smaller, as had been noticed, than in an ordinary engine of the same power; and the same remark applied even more forcibly to the number of working joints in the engine. The joints in the valve gear, which were frequently a source of trouble in other engines, appeared in this to be absolutely free from wear, and had never given the slightest trouble. The air-pump being here worked direct from the piston-rod of the steam cylinder was without any joints at all; whereas in an ordinary engine there were commonly several joints involved in the connection for driving the air-pump.

The CHAIRMAN proposed a vote of thanks to Mr. Porter for his paper, which was passed.

The following paper was then read:—

DESCRIPTION OF THE AMERICAN DOVETAILING MACHINE.

By Mr. JOHN ROBINSON, of Rochdale.

This Dovetailing Machine, which is the invention of Mr. S. T. Armstrong of New York, was shown at work at the recent Paris Exhibition. It is constructed so as to cut out the dovetail joints in woodwork by means of the continuous rotation of compound circular saws of peculiar form, which finish the joints completely, without the use of any chisels or cutters, as was requisite in previous machines for the purpose. The same machine cuts both the pins and the holes of the dovetails in succession, by a simple change of adjustment, so that their pitch and dimensions necessarily correspond exactly, and make a correct joint in every case.

The machine is shown in Figs. 1 to. 5, Plates 21 to 24; Fig. 1 is a side elevation, Fig. 2 a back elevation, and Fig. 3 a plan.

The two compound circular saws A and B, each about 2 feet diameter, are placed inclined to one another at an angle of 18°, Figs. 2 and 3, corresponding to the inclination of the two sides of the dovetail pins; and they are geared together by two bevilled toothed rings upon their inner faces. The saws run loosely upon two short fixed axes; and one of them A is driven by the main driving shaft C through the intermediate bevil wheel D, which gears into a corresponding toothed ring on the outer face of that saw; the second saw B is driven by the first one A.

The two inclined axes of the saws, one of which is shown separately at E in the section, Fig. 5, Plate 24, are fixed upon the faces of two small circular discs F; these discs are parallel to one another, and each has a spindle G on the outer face. The two spindles are both in the line of the driving shaft C, and turn in two sockets in the machine frame. The discs F F have two toothed sectors I I fixed upon them, which gear with two pinions on the shaft J J, so that on turning this shaft by the handle H the inclined axes of the two saws are turned round simultaneously through a quarter revolution; the direction of their inclination is thus changed from vertical to horizontal or the reverse, and the point of contact of the two saws is rolled round through a quarter of a revolution. The connection with the driving shaft C for driving the saws is preserved during this change of position by the intermediate bevil wheel D continuing in gear, whilst rolling round into the position shown by the dotted lines in Figs. 1 and 2, the wheel D being carried upon the arm of one of the toothed sectors I.

The object of this movement is to change the action of the saws from cutting the pins to cutting the holes of the dovetails. The wood to be cut is clamped down upon the table K, Figs. 1 and 3, which is placed radially to the saws, so that the cuts are at right angles to the face of the wood; and when the dovetail holes are to be cut, the two saws are required to be at their full inclination to each other in plan, but parallel on the edge of the wood, as shown in Figs. 8 and 9, Plate 25, so that one saw cuts the right-hand side and the other the left-hand side of each dovetail hole; and the two oblique axes of the saws are made for this purpose at the inclination to give the angle of 18° between the two saw faces. But when a rotation of a quarter of a circle is given to these two axes by means of the toothed sectors I I, the direction of their inclinations is then brought at right angles to the face of the wood to be cut, as shown in Figs. 6 and 7; and the edges of the saws, where in contact with the wood, are parallel to one another in plan but inclined in elevation, so as to cut the dovetail pins with parallel sides on the face of the wood, Fig. 6, but inclined on the edge of the wood, Fig. 7. By this means the pins and holes of the dovetails are formed at exactly the same inclination, by the simple expedient of cutting hem at two different points of the circumference of the saws, at ight angles to each other.

Each saw cuts one half of a pin or hole in a single revolution. 'he saw blade is made plain for the first three-quarters of its ircumference, like an ordinary circular saw, but with a spiral utline gradually increasing in diameter, as shown in Fig. 4, 'late 24, so as to increase the depth of cut continuously until the ottom of the dovetail is reached. The last quarter circumference f the saw blade is made truly circular, but has the cutting dge bent over at right angles, so as to cut at the side, r cross-cutting the bottom of the dovetail; and the lateral rojection of the flanged blade gradually increases until it is qual to half the width of the bottom of the hole. For cutting e pins of the dovetail, the two saws being then parallel in plan, s shown in Fig. 6, Plate 25, the flanged saw blades have the dge bent over inwards exactly at right angles, for cross-cutting e bottom of the dovetail; but for cutting the holes, the anged blades are bent over outwards to an angle of 81°, as shown Fig. 8, the two saws being then inclined at 18° towards each her in plan.

In order to traverse the wood for obtaining a succession of its, the table K on which it is clamped is traversed across in ont of the saws with a continuous feed motion by means of the ed-screw L, Figs. 1 and 3, driven by spur gear from the main aft C; and the blade of each saw, instead of being at right gles to the axis upon which the saw revolves, is set inclined ke a screw thread, with 1 inch pitch, that being the intended tch of the dovetails. The bed-screw L also traverses the wood inch forwards in each revolution of the saws; and the saws d the wood are consequently made to traverse exactly together, ch saw following up its own cut correctly, until the cut is mpleted at the end of one revolution of the saw; and the w then commences the next cut at the pitch of 1 inch. The cond saw B does not commence cutting until the first saw A s advanced a certain distance in the work, as shown in Figs. 6 to

13; and it continues cutting throughout at the same distance behind the first saw, but completes all the pins or holes at the end.

The saw blades are made in short segments, each 6 inches long, as shown in Fig. 4, and are fixed in their places by fitting into a turned recess M M in the circumference of the cast-iron boss B; they are held in their places by a series of segment plates N N at the back, tightened up by two bolts each. The saw segments are readily released and changed, when it is required to set the machine for a different size of dovetail, or to change from cutting the pins to cutting the holes; and five different sets of blades are kept for this purpose, to give the extent of range in dimensions of dovetails that is required with each machine; the several sets vary proportionately both in the plain and the flanged portions of the blade.

In changing the machine from cutting the holes to cutting the pins of the dovetails, the two saw blades require a slight adjustment endways relatively to each other, in order to take up the slack that would be caused in the fit of the dovetails by the thickness of the saw-cuts themselves, and to make the pins fit true and tight in the holes without any shake. This adjustment is obtained by simply rotating the second saw B a certain distance round upon its axis E, Fig. 5, the toothed driving ring R R being for this purpose made loose upon the boss B of the saw, and locked to it by the pin P for driving the saw. As the circumference of the saw blade is itself in the form of a screw thread of 1 inch pitch, the effect of turning the saw round upon its axis E is to shift endways the point of commencing the cut; and by this means therefore the cut of the second saw is made to follow that of the first at exactly the required distance. The ring R R, Fig. 4, is marked with graduations corresponding to the several adjustments required for changing the machine from one size of dovetail to another, or from cutting the pins to cutting the holes of the dovetails; and the adjustment includes the required allowance for clearance, to make the pins and holes fit together with any degree of tightness that is desired, without requiring any dressing by hand. The whole change is so readily made hat in three minutes the machine can be altered from one size f dovetail to another, and got to work again.

The saw segments are all made exact duplicates of one another ı the portions fitting on the boss of the saws; and consequently in ıe wear of the saws, as the segments become gradually reduced in iameter by the sharpening, they are simply shifted each to the djoining place in the circumference of the saws, a new segment eing required only for replacing the last or largest flanged segment. 'he change also from the flanged to the plain segments is made by ling down plain teeth in the first flanged segment when worn out.

The table K carrying the wood, Fig. 1, is made with a hinge ıovement, so that it can be inclined at an angle of 45° to its usual ıdial position, as shown by the dotted lines at T, for the purpose f cutting concealed dovetails, in which the two pieces of wood form mitre joint at the outer angle, the dovetails being concealed, as ıown in Figs. 10 to 13. No other alteration of the machine is equired for this work, as the bottoms of the pins and holes are then nished correctly at 45° by the cut of the saws.

The table K is mounted upon two slides at right angles to each ther, like the slide-rest of a lathe; the lower slide receives the averse feed-motion from the bed-screw L, and the upper slide is ıoved inwards towards the saws by the hand lever U, Figs. 1 and 3, ırough a distance equal to the depth of the dovetails. The upper ide also carries a half nut, which gears with the traverse screw L; that when the wood is advanced up to the saws by the hand ver U, the nut is at the same time thrown into gear with the rew L, causing the traverse feed-motion of the wood to commence.

A scriber S, Figs. 1 and 3, is used to mark off on the underside the wood the bottom line of the dovetail pins and holes, in lvance of the saws, to prevent the edge of the wood from being roken on the underside. This scriber serves also as a gauge for tting the edge of the wood to be cut, which is first clamped down pon the table K with its edge level with the scriber S, Fig. 3; and ıe wood being then moved inwards towards the saws by the hand ver U, this gives the correct depth of cut for the dovetails.

The working speed of the machine is 150 revolutions per minute, one pin or hole of the dovetail being cut at each revolution.

Mr. **Robinson** exhibited one of the circular saws complete from the dovetailing machine, and also a number of specimens of the dovetails cut by the machine, showing the several stages of the operation, in the case both of ordinary dovetails, and concealed dovetails for such purposes as cabinet makers' work.

The **Chairman** enquired whether the specimens of dovetails exhibited had been dressed by hand after leaving the machine, in order to make them fit together so true and tight.

Mr. **Robinson** replied that none of the work had been touched at all by hand, and it was exactly as it came from the machine. The fit of the joints was readily adjusted by the machine to any degree of tightness that was desired, by simply turning the second saw upon its own axis through a smaller or larger arc, at the time of changing from cutting the pins to cutting the holes; by this means the fit was made much more correct and uniform than was possible in any hand work.

Mr. H. **Chapman** enquired whether the machine was found to answer for cutting hard woods, and what was the hardest wood that had been tried.

Mr. **Robinson** replied that the hardest wood in which he had cut dovetails by the machine was elm, which when dry was very hard; and in the hard woods the work was cut still cleaner than in the softer woods. The specimens exhibited were all cut in deal, for the purpose of showing the character of the ordinary work produced by the machine, which was mainly employed upon deal for making packing-cases and other large boxes.

Mr. E. A. **Cowper** said he had seen the working of one of these machines in London, and an important advantage obtained in that mode of cutting dovetails was that the strength of the joint was reatly increased, and in fact the maximum strength was got out of he material, because the dovetails and recesses could be spaced niformly along the entire line of the joint, so as to make the dovetails s wide as the spaces, instead of having only a few small dovetails laced wide apart, as was often the case in joints dovetailed by hand. The construction of the machine indeed prevented any undue width f spaces being left between the pins; and the spacing to which the nachine was originally adjusted was continued with complete niformity through the whole of the work. In regard to hard voods he believed the difficulty experienced in previous dovetailing nachines had been that the hard wood could not be cut without plitting it; in the present machine it appeared that the first three-quarters of the circumference of the saw blade was employed in cutting the depth of the dovetail, and only the last quarter was left for doing the whole of the cross-cutting; and he suggested that for cutting hard woods it might perhaps be desirable to have a greater ength of the circumference flanged over for the cross-cutting, so that there should be less work upon each tooth of the saw, thereby giving a smoother cut in the wood. The plan of flanging the saw blade at right angles for cross-cutting the bottom of the dovetails was certainly a very ingenious idea; as was also the arrangement for allowing the work to be traversed continuously through the machine, by making the saw blade inclined like a screw thread, so as to follow the traverse of the work whilst cutting the dovetail at the same time; and this he considered the great novelty of the machine. The mode of fixing the segmental saw blades afforded great facility for changing them for a different set whenever required; and he had seen the entire set of blades in the pair of saws taken out in 1¾ minutes, and a new set put in and fixed in 2 minutes more, ready for the machine to start working again. The machine was altogether most ingeniously contrived, and he thought it would be found very useful and efficient, particularly for making packing-cases and boxes, as the wood might be made thinner, and yet the same strength be obtained at the joints.

The CHAIRMAN enquired where the flanged saw blades were made that were required for the cross-cutting. He asked also whether the machine was extensively used in America, having originated in that country.

Mr. ROBINSON replied that he was informed there were now more than 2000 of these machines at work in America. The saw blades, both plain and flanged, were made at his own works by the same men who fitted the machines together; and in reference to the greater amount of work put upon the teeth in cross-cutting in hard woods, it was not necessary to use a greater arc of the circumference for the cross-cutting in that case, but it was only a question of the increased fineness of the saw teeth; and with teeth sufficiently fine the cut was made smooth and clean, without any risk of splitting the wood. The saw teeth were required of course to be particularly well tempered for working in hard woods; and the machine had done a great deal of work in cutting dovetails in hard wood.

The CHAIRMAN moved a vote of thanks to Mr. Robinson for his paper, which was passed.

The following paper, communicated through Mr. C. William Siemens, was then read:—

ON AN IMPROVED CUPOLA FOR IRON FOUNDRIES.

By Mr. JACOB EICHHORN, of London.

In Cupola furnaces the blast enters generally either through uyeres, or through horizontal or vertical slits at the sides of the upola; but a disadvantage attends these arrangements, inasmuch s the blast being too cold at the beginning to combine at once with e carbon of the fuel, must first be diffused through the fuel before can burn, and the greatest heat is therefore produced at a point tuated above the tuyeres. The height of this point varies with e respective quantities of fuel and of blast that are introduced; nd when sufficient fuel is supplied, the point of greatest heat will e situated at the level where all the oxygen in the blast has become arbonic oxide. It is found in practice that the range of level of is point extends over several feet, according to the quantity of el used, the height being generally about 3 feet above the level the tuyeres; but in the cases mostly met with in foundries ere is not a sufficient supply of fuel close to the tuyeres openings where the blast enters, and in these cases therefore e blast does not meet with sufficient fuel for complete ombustion until it arrives at the upper layers of the fuel, and it nsequently passes the hot metal and causes it to be burnt. The aste upon the metal put into the cupola amounts to from 5 to 10 er cent. generally in these furnaces; and the rapid burning away d destruction of the lining extends over a height of 5 to 6 feet from e hearth. Another disadvantage, resulting from the necessarily nfined space occupied by the tuyeres or blast openings, is that the ast, being thereby concentrated, acts upon the carbon contained the iron, and consequently deprives the iron more or less of its sibility.

To remove these disadvantages of the ordinary construction of cupolas, a plan has been devised and carried out successfully by Mr. Henry Krigar of Hanover, which forms the subject of the present paper, and aims at the accomplishment of the following objects:—to concentrate the heat in the lower part of the cupola, where there are facilities for easily repairing the furnace lining, and to render the action of the cupola uniform throughout the operation of melting; to give the hearth such a size that the column of fuel between the layer of melted metal and the level where the blast enters the interior of the furnace may vary but little in height, so as to limit the range of the destructive action upon the furnace lining; and to ensure the blast being taken up by the carbon of the fuel from the moment of its entering the furnace, and thereby prevent it from injuring the heated metal by oxidising it.

The construction of this cupola is shown in Figs. 1 to 5, Plates 26 to 29; Fig. 1 is a front elevation, Fig. 2 a vertical section from front to back, Fig. 3 a vertical section from side to side, and Figs. 4 and 5 are sectional plans at different levels.

The vertical shaft A A of the cupola is made rectangular in form, either square or oblong, as shown in the plan, Fig. 4, and parallel or with very little taper in height, so as to avoid any prominent part upon which the flame could strike, and which would be exposed to rapid destruction. A backing of sand is used behind the brickwork to concentrate the heat in the cupola. The shaft A is supported at front and back by arches B B over the lower chamber C C; and at the sides of this chamber is also a backing of sand, as shown in Fig. 3, to keep the heat in. Over this backing and round the bottom of the shaft A runs the air passage D D, into which the blast is delivered from the two air mains E E; and the blast entering through this passage cools the brickwork of the cupola, and becomes heated itself; it then passes down into the melting chamber C C through the two long slots F F in the roof, one at the front and the other at the back, extending the whole breadth of the hearth, as shown in the plans, Figs. 4 and 5. These slots are constructed by leaving a space of 4½ inches width between the outer arches G G, Fig. 2, and the inner arches B B that carry the shaft A;

the length of the hearth H from front to back is consequently made greater than the breadth. The front of the cupola is closed by an iron door K on hinges, extending the whole breadth of the hearth; and a smaller door L is placed at the back, to facilitate the drawing of the cupola by inserting a rake at the back; by this means the drawing of the cupola can be accomplished regularly within 3 or 4 minutes.

For starting the cupola, about 1 to 1½ cwt. of coke is placed on shavings or some burning coke upon the hearth, and more is added by degrees from the front door, until all the coke intended for the first filling is put in. The door K is then closed, being first wetted on the inside; and the tapping hole J is formed as usual by placing clay round a wetted stick. The whole height of the door is then plastered on the inside with a mixture of clay and sand, the door being set forwards about 5 inches in front of the breast of the furnace, to allow space enough at top for the furnace man to get his arm in for lining the door; and the space at top is afterwards closed with bricks. This mode of closing is adopted for cupolas working with a pressure of blast of from 4 to 7 inches of water; but where the blast is stronger a wall of coke is first built up inside the melting chamber C and wetted; and the door being shut and secured with wedges, the space between the door and the wall of coke is then filled with foundry sand rammed in.

The amount of filling that is put in for starting the cupola varies with the size of the cupola and the quantity of melted metal that the hearth is intended to contain at once; but the amount is always much less than is usually employed in other cupolas. One of the new cupolas capable of melting 3 tons of iron per hour requires a filling of 2¾ cwts. of coke for starting it, or 3¾ cwts. when it is intended to keep the whole of the melted metal in the hearth, to be tapped all at once. Upon this filling a charge of 8 cwts. of iron is added from the top of the cupola shaft, and then about ½ cwt. of coke, and again a charge of 8 cwts. of iron followed by ½ cwt. of coke; and the same in succession until the whole charge is put in, filling up the shaft A to the top, as shown in Fig. 2. After the casting, a certain quantity of the coke is drawn out unconsumed. The average quantity of coke consumed is 1½ cwt. or 168 lbs. per ton of iron melted, when only 3 tons are melted in each charge; and the consumption is 147 lbs. per ton when charges of 6 tons are melted; and 140 lbs. per ton with heavier charges.

The metal melted in this cupola is found to be very fluid; and indeed so fluid that, in the cases where in an ordinary cupola seldom more than one half of cast-iron scrap is used, this cupola bears under the same circumstances the addition of fully three quarters of scrap. At the same time the softness of the metal is retained; or, as it is commonly termed, the metal is clean. If the cupola be allowed to stand without blast for one hour after the filling is completed, and the blast be then turned on, the metal begins to run down to the tapping hole six minutes afterwards; but if the blast be admitted immediately on completion of the filling, without allowing the cupola to stand, the metal may be made to run from the tapping hole within one hour from the time that the cupola was empty before the filling commenced.

This cupola has the advantage of allowing the whole of the metal melted during one hour to be retained in the hearth; this result however is not obtained by increasing the height from the bottom of the hearth to the crown of the arches carrying the shaft, but by increasing the length of the hearth from front to back, as shown in the longitudinal section, Fig. 2. If the height from the bottom of the hearth to the arches is made too great, the metal loses the great fluidity that distinguishes the working of this cupola. The height from the tapping hole J to the charging opening at top of the shaft A is from 13 to 14 feet. As the construction of the cupola causes it to work hotter than ordinary cupolas, it requires a smaller area of shaft than an ordinary cupola for the same blast and yield, the reduction being in the proportion of about 3 to 7; any existing cupola shaft can therefore be altered to this plan, and will still yield more metal than before in the same time.

The quantity of blast required is 30 cubic feet per second, reduced to the pressure of the atmosphere, for each ton of iron melted per hour. The pressure of the blast used may be as low as 4 to 5 inches, but a pressure of 8 or 9 inches is generally adopted. Whether this or a still higher pressure is used, no further economy of fuel is obtained, but only a greater quantity of metal is melted down in the same time by the same furnace.

With regard to the wear and tear of the cupola, the lower part of the shaft A is exposed to the greatest destruction, but that is the only portion which suffers more than the lining of an ordinary cupola, and it is easily accessible for repair. The coke falling from the shaft into the melting chamber C C, Fig. 2, stands there in a heap, upon which the blast rushes through the two transverse slots F F in the roof; and the heat from the burning fuel being radiated into the air passages D D, the blast becomes prepared for combining rapidly with the carbon of the fuel, before it has an opportunity of coming in contact with the melting metal and wasting it by oxidation; and the action of the blast is finished, as may be judged from the appearance of these cupolas, at a level of only about 14 inches above the crown of the arches B B. This corresponds to the portion of the cupola that requires to be renewed about every three to four months; and a small arched iron bar of 2 to 3 inches width, remaining constantly in its place in each arch B, allows of the arches being readily replaced at any time without the introduction of centering. The shaft A suffers very little wear itself, and after six months' work it can only be said that the bricks are strongly glazed. When the arches B B are replaced every three to four months, the face only requires patching or plastering up once or at most twice a week; and only about half or little more of the repairing material is required that would be necessary in an ordinary cupola. The total cost of wear and tear therefore does not at most exceed that of the ordinary cupolas, while there is less trouble in keeping the improved cupola in repair.

With regard to economy of metal, the results of the working of this cupola are found to be that in melting pig iron, such as Calder No. 1, the loss amounts to 3·4 per cent. on the metal weighed in; and when mixed with three fourths of railway-chair scrap, the loss only 2·2 per cent.

Mr. C. W. SIEMENS said that he had been much struck with the working of the new cupola on first seeing it several months ago; and the main feature in it which appeared to him of particular advantage was the improved mode of introducing the blast, through the air passages and arches at the bottom of the vertical shaft. In an ordinary cupola, when the blast went in straight through the tuyeres it met with the iron and the coke promiscuously, and the melted iron falling in drops into the hearth became oxidised or burnt by encountering the uncombined oxygen of the blast; the quantity of cinder on the top of the melted metal in the hearth was thereby increased, and metal wasted. In the new cupola however the blast on entering did not at once meet the iron, but it first came upon a heap of red-hot coke, by which the oxygen was partially converted into carbonic acid; and as this passed upwards through the ignited materials above, the greater portion took up a further supply of carbon from the coke, and became reduced to carbonic oxide, while only a small portion parted with some of its oxygen to the melted iron; the metal thus became less burnt than when exposed to the direct action of the uncombined oxygen in the blast. Another peculiarity of the new cupola was the large size of the hearth, on account of its increased breadth, which allowed of a large accumulation of melted metal being contained in the hearth, without increasing its distance below the level of the zone of greatest heat in the shaft of the cupola. The metal in the hearth was thus kept thoroughly hot, up to the time of tapping the cupola. As the combustion was completed so close to the bottom of the cupola shaft, the gases escaping from the top came off more thoroughly deprived of their heat than would otherwise be the case; so that the effect in that respect was similar to what would be obtained with an ordinary cupola of considerably greater height. The bottom of the vertical shaft was certainly more liable to suffer from wear and tear in this construction than in an ordinary cupola, because the arches were evidently exposed to a more severe action of the heat; and it would be necessary to ascertain by continued working what was the duration of this part of the cupola. The worn portions however were easily accessible for repair; and the iron plates on which the arches were built remained uninjured, being themselves not exposed to the excessive heat.

Mr. F. W. **Webb** said he had used one of the improved cupolas at Bolton during the past few weeks for melting down iron for the Bessemer process, for which purpose the metal was required to be much hotter than for ordinary castings. The cupola was worked for tapping out 2 tons make of metal at once, and the fuel employed being Durham coke, the quantity required for filling in was 4½ cwts.; after which the charges were alternately 7½ cwts. of iron and 60 lbs. of coke until the charging was completed to the top of the cupola shaft. This gave the proportion of coke to iron as 1 to 14, neglecting the filling in; and when the cupola was raked out after tapping, some of the fuel remained available for use in filling in for the next charge. In one of the ordinary cupolas previously employed the consumption of fuel in working 6 ton charges was 4½ cwts. per ton of iron, including the filling in, the fuel in that case being Lancashire coke from Accrington. The wear and tear in the new cupola he anticipated would be found to be rather greater at the bottom of the vertical shaft than seemed from the paper to be expected; but at present the cupola at Bolton was working very well, and one advantage found was that the iron was obtained very hot from it.

Mr. E. A. **Cowper** observed that he had seen the new cupola at work in London, and was very much pleased with it; and he thought the consumption arrived at of only 140 to 160 lbs. of fuel per ton of iron melted was really a very small amount. The lowest consumption that he was acquainted with previously in other cupolas was 2 cwts. of Elsecar coke per ton of iron; and that result was only obtained with a large cupola, 3 feet 4 inches in diameter, blown with two 10 inch tuyeres and 7 inches column of blast, and melting about 9 tons of iron per hour: a cupola 2 feet 9 inches diameter with two 6 inch tuyeres and 7 inches column of blast he had found would bring down 6 tons of iron per hour. In the new cupola the blast on entering became heated up at once to a high temperature by passing through a heap of red-hot fuel; the oxygen was thus mostly combined with carbon before meeting the melted iron dropping into the hearth, and the level of greatest heat was also brought down nearer to the hearth. The iron was therefore less liable to be burnt, having less height to fall through the entering blast; and the large size of the hearth in proportion to the rest of the cupola allowed of a large quantity of melted metal being kept hot ready for tapping. The cupola appeared likely he thought to stand very well in regular work, and it certainly gave promise of being decidedly economical.

Mr. J. **Fernie** thought the height of the new cupola was hardly so great as might be desirable for the greatest economy; and in the case of other cupolas any alterations made in this respect had been in the direction of increasing the height rather than the contrary. The economy of fuel obtained with the new cupola appeared to be about the same as in the cupola the first form of which he had described at a previous meeting (see Proceedings Inst. M. E. 1856, page 49). In that cupola the blast was admitted through a large number of holes arranged in a belt all round the cupola, instead of the ordinary two large tuyere holes; and the consumption of coke was brought down to only 1¼ cwt. per ton of iron melted, when the cupola was kept going in continuous work. Moreover with the number of smaller holes the blast was more diffused, and the iron was less burnt in consequence.

Mr. C. C. **Walker** thought the form of a cupola had a great deal to do with its economy. He had lately been making some experiments upon this question with an ordinary cupola, 6 ft. 6 ins. high from the hearth to the charging hole, and melting down about 14 or 15 cwts. of iron per hour, with two tuyeres, one on each side, blowing in the ordinary way. The consumption of fuel was rather less than 3 cwts. of Durham coke per ton of iron melted, and a considerable quantity of flame came out at the top. The charging hole was then raised 18 inches, and it was found in a trial of three or four weeks duration that the consumption was thereby reduced to 2¾ or 2½ cwts. of coke per ton, while the flame previously escaping at the top had nearly ceased. He had further made trial of the plan which had been referred to, of introducing the blast by means of two rings of holes round the cupola, eight holes in all, instead of a single pair of tuyere holes; and at the same time the inside of the cupola was altered to a shape more like that of a blast furnace, by narrowing it in diameter for about 15 inches height, the narrowing commencing at about 15 inches from the floor or hearth. The result then obtained in a trial of several weeks was certainly a great economy of fuel, the consumption being only 1½ cwts. of coke for melting down 1 ton of iron, and the flame at the top ceased; and he understood that, in another trial of the same plan of blowing, the consumption had been found to be even as low as 1¼ cwts. of coke per ton of iron, though he doubted whether the heat of the melted iron was sufficient for ordinary castings with so low a consumption of coke. This experiment did not indeed determine whether the economy thus obtained was due to the mode of blowing, or to the narrower bottom of the cupola; but he was led to believe that the latter was the main source of advantage, because he had been informed that where the increased number of blast holes had been tried, independent of any alteration in the shape of the cupola, no advantage had been experienced in economy; and moreover, in the case of the Bessemer process, the sets of numerous small holes originally employed for introducing the blast had now been replaced by two single holes only in each converting vessel, which were found equally effective for blowing the metal. It appeared therefore that the narrowing of the bottom of the cupola resulted in as great an economy of fuel as that obtained with the new cupola described in the paper, and he did not see that there were any other important advantages in the new cupola; he asked what description of coke had been used in it, and also what arrangement was made for letting the slag run off from the surface of the melted metal in the hearth. With regard to the air passages shown in the drawings for admitting the blast in the new cupola, he thought it was questionable whether much advantage would really be gained from that arrangement in heating the blast before it reached the fuel, because the air passed with such rapidity that there was hardly time for it to become much heated in so short a distance.

Mr. **Eichhorn** thought that although the blast entered the cupola at so great a velocity, it must become highly heated in the air chambers, because the outside of the cupola even at those places was so hot that it was impossible to bear the hand upon it; which would hardly be the case if the blast remained cold. The coke which he had used in the cupola in London was the ordinary Newcastle coke; and the slag was as usual allowed to run off through a slag hole in the door containing the tapping hole, as shown in the drawing. In respect to the question of economy, there was an important reduction in the waste of iron in the new cupola, the loss being only 3·4 per cent. in melting pig iron such as Calder No. 1, and only 2·2 per cent. when mixed with three fourths of railway-chair scrap; whereas the average waste in ordinary cupolas was found to be 5 per cent. with the same materials.

Mr. C. C. **Walker** observed that the waste of iron depended partly upon its quality, as well as upon the construction of the cupola in which it was melted; and in the case of the Cleveland iron the waste was so considerable that he understood at some ironworks its use had been abandoned, and a more expensive but less wasteful description of iron adopted instead, though he could not say that was his own experience.

Mr. C. W. **Siemens** thought that as regarded waste of iron the construction of the new cupola was decidedly advantageous; because not only was the zone of greatest heat brought down nearer to the hearth, whereby the iron dropping into the hearth was less exposed to the blast, but also the melted metal in the hearth had a large part of its surface covered by the heap of fuel lying upon it, which effectually protected it from oxidation.

The **Chairman** enquired how long the new cupola had been in use, and to what extent it was now employed; and what was the average daily quantity of iron melted.

Mr. **Eichhorn** replied that the cupola had now been at work for six months at Messrs. Whitley and Son's foundry in London, and for about eighteen months in Germany, where it was extensively in use at many ironworks. The quantity of iron melted in the one in London had been from 1½ to 3 tons per day, and the average might safely be taken at 2 tons per day during the whole period; the same results were also obtained with the cupolas at work in Germany.

Mr. T. **Claridge** observed that in some experiments which he had made with an ordinary cupola he had found great economy was occasioned by increasing the height. The original height had been only 7 feet from the tapping hole up to the charging hole, and at that time the materials were always at a red heat at the charging hole. But when the height was increased to 14 feet there was only a black heat at the charging hole, and the heat passing up from the lower portion of the cupola was usefully employed in heating the descending materials above. In this case the diameter of the cupola was 2 feet, giving the proportion of 7 to 1 between the height and the diameter; and he considered the height from the tapping hole to the charging hole should always bear a certain proportion to the diameter, and he believed the proportion of 7 to 1 was the most satisfactory for economy of fuel. With this proportion he had found that the previous consumption of 3 cwts. of coke per ton of iron had been reduced to only 1¼ cwts. in the higher cupola; and the iron brought down was very much harder in quality than had previously been the case with the greater consumption of coke.

The **Chairman** remarked that a constant proportion of 7 to 1 between the height and the diameter of a cupola would require the larger cupolas to be much higher than was generally the case at present; a cupola of 3 feet diameter would then have to be 21 feet high up to the charging hole.

Mr. T. **Claridge** said that 3 feet diameter was a very large size for a cupola; but if that size were adopted he considered the same proportion should still be adhered to, and the height should certainly not be less than 21 feet; if it were less, there would be a corresponding diminution of economy, owing to the greater quantity of heat escaping to waste at the top. The objection to a great height of cupola was the increased time and labour of raising the materials for charging; and mechanical arrangements would be required for the purpose wherever the height was considerable.

With regard to the plan which had been referred to of blowing a cupola through a number of small holes round its circumference, he believed this was not intended to be used in substitution for the two large tuyeres ordinarily employed, but in conjunction with them, the smaller holes being situated about 3 feet height above the tuyeres; in first starting the cupola to work the two tuyeres were used alone for a short time, until the iron began to run down, and then the blast was admitted through the upper holes. The advantage of that plan appeared to him to be that a greater volume of blast was thereby blown into the cupola, and distributed over a greater area, in consequence of which the iron was brought down with greater rapidity.

The CHAIRMAN enquired in what manner the quantity of blast supplied to the new cupola had been ascertained; it appeared from the statement in the paper that the supply of blast was as much as 100,000 cubic feet per hour per ton of iron melted.

Mr. EICHHORN replied that the quantity of blast had been estimated by calculation from the pressure and the area of the blast main, by means of the ordinary formula $Q = C \times A \times V$, Q being the quantity of blast supplied per second in cubic feet, A the area of the blast orifice in square feet, V the velocity of the issuing blast in feet per second, and C a coefficient for the loss by friction in the blast main. The value of this coefficient, deduced from experiments, was given by Wiesbach as 0·7; and putting h to represent the height in inches of the column of water indicating the pressure of the blast in the main, and taking the specific gravity of atmospheric air as $\frac{1}{800}$ compared with water, the above formula became $Q = 0{\cdot}7 \times A \times 8 \sqrt{(800 \times h \div 12)}$, expressing the velocity in terms of the height in inches; or

$$Q = 45{\cdot}7 \times A \times \sqrt{h}$$

that is, the quantity of blast supplied in cubic feet per second was the product of the area of blast orifice in square feet, multiplied by the coefficient 45·7 and by the square root of the number of inches height of water column indicating the pressure of blast in the main. The pressure of blast which had been found best to be employed in the cupola was 4 to 5 inches column of water. If the supply of blast to ordinary cupolas were calculated in the same way, it would be found to be quite as great as in the new cupola. In the instance the cupola now at work in London, the same blowing fan was ed as for the ordinary cupola previously employed, and the area of e furnace was now reduced in the proportion of 7 to 3 for melting e same quantity of metal.

The CHAIRMAN proposed a vote of thanks to Mr. Eichhorn for his per, which was passed.

The Meeting then terminated.

PROCEEDINGS.

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28 and 29 July, 1868.

The Annual Meeting of the Members was held at the hilosophical Hall, Leeds, on Tuesday, 28th July, 1868; Joseph hitworth, Esq., Past-President, in the Chair.

The Minutes of the last Meeting were read and confirmed.

The Chairman announced that the Ballot Lists had been opened, d the following New Members were duly elected:—

MEMBERS.

George Edward Belliss,	Birmingham.
George Buckton,	Leeds.
William Cochrane,	Newcastle-on-Tyne.
John J. Derham,	Blackburn.
Alfred Dodman,	Lynn.
Robert William Eddison,	Leeds.
Arthur Firth,	Leeds.
John Forster,	Barrow-in-Furness.
John James,	Ebbw Vale.
Peter Kerr,	Paisley.
John Hawthorn Kitson,	Leeds.
John Lea,	Bowling.
Benjamin McKay,	Birmingham.
Charles O'Connor,	Bath.
Arthur Paget,	Loughborough.
Frederick Parker,	Leeds.
Frederic William Rafarel,	Cwmbran.
Edward Antoine Sacré,	London.
George Lamb Scott,	Manchester.

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CHARLES SCRIVEN, . . .	Leeds.
SAMUEL TAYLOR, ...	Leeds.
JOHN THOMSON, ...	Glasgow.
ROBERT THORNEWILL, . . .	Burton-on-Trent.
HERBERT WALLIS, . . .	Bradford.
JOHN RICHARDSON WIGHAM, . .	Dublin.
REGINALD WIGRAM, . . .	Leeds.
LINDSAY WOOD, ...	Hetton.

ASSOCIATES.

MONTAGUE BEALE, ...	London.
THOMAS BRIGHT MATTHEWS, . .	Sheffield.

GRADUATE.

JOSEPH HARTLEY WICKSTEED, . .	Leeds.

The following paper was then read:—

DESCRIPTION OF THE MACHINERY FOR THE MANUFACTURE OF THE BOXER CARTRIDGES.

By Mr. THOMAS GREENWOOD, of Leeds.

During the last few years there has been more activity, ingenuity, and competition amongst the inventors and producers of military small arms, than in any other period since the invention of gunpowder. The experience gained during the recent terrible American war does not seem to have been adequately studied in Europe; and it was only when the dire effects were rendered evident of the breech-loading needle-gun, which was so efficiently handled by Prussia in the still more recent German war, that the leading governments of Europe became fully aware of the importance of breech-loading arms. It is true that in this country, shortly before the decisive German battles, it had been determined to change the Enfield rifles into breech-loaders; but no decided steps were taken to carry this resolution into effect. At the present time however every power in Europe is engaged in perfecting and carrying out one or other of the many systems of breech-loaders; and the various merits of the different kinds are criticised with an eagerness which proves the value now attached to the efficiency of this description of arm.

The "magazine rifle," or as it is more commonly called the "repeating rifle," has not yet received the attention it deserves, owing to its more complicated mechanism and the more careful training consequently required by the soldier in order to use it perfectly. The adoption of this rifle however can only be a question of time; for when it is remembered that less than seven years ago the idea of a breech-loader was considered quite impracticable by the leading military men, both in this and other countries, it is evident that only a small amount of further progress is required from the present stand-point of the breech-loader, in order to arrive at the same conclusions respecting the repeating rifle which have already been attained in regard to the single breech-loader.

But however important it may be to select the best rifle, this question is so bound up with the system of cartridge employed, that the rifle will frequently have to be modified to suit the cartridge. The first attempt to make a breech-loader failed in England, because it was wished to use the same cartridge as that adapted to the muzzle-loader; and it was only when this idea was given up that any real progress was made in perfecting the breech-loader. The attempts to stop the breech of the gun by mechanical means utterly failed, in all cases where the stopper was left exposed to the action of the powder; and this is the most serious defect in the Prussian needle-gun, in which a cartridge case is used made of paper or other self-consuming material. This gun cannot be fired from the shoulder, because the gas escapes at the breech in such a quantity as to injure the eyes of the soldier; and it is therefore fired from the hip, which must seriously interfere with its efficiency in war. The same defect exists also in the chassepot gun, which in principle closely resembles the Prussian needle-gun, especially in some of its worst features, such as having the fulminate powder immediately in the rear of the bullet itself and in front of the gunpowder, and using a paper cartridge, which leaves a residuum in the chamber of the gun; this residuum fouls the mechanism, and consequently impedes its working. With the fulminate in front of the gunpowder, the needle having to pierce through the whole length of the charge of gunpowder before reaching the detonating cap at the front end, is liable to get bent, in which case the point of the needle misses the fulminate, and the result is a miss-fire. The French war department found this defect out after they had contracted for 800,000 chassepot rifles. It is evident therefore that even a first-rate breech-loading rifle will be comparatively worthless, unless the cartridge is equally efficient.

For the Manufacture of Cartridges, simple though they apparently are, numerous ingenious schemes have been devised; and it is only after many failures that anything like a serviceable cartridge has been produced. The requirements of a good cartridge are: first, it must not miss fire; second, it must prevent the escape of any gas backwards, that is it must be of sufficient strength not to burst with the explosion of the gunpowder; third, the case must be capable of being easily extracted after firing; fourth, it must be to a considerable extent impervious to damp, though not perfectly water-tight; and lastly, it must be of a cheap and light construction.

The system of breech-loading cartridges for military purposes has been divided into two classes, called "rim-fire" and "central-fire." The Rim-fire cartridge, of which an illustration is shown double full size in the sections, Figs. 1 and 2, Plate 30, is generally made out of a copper or brass disc, drawn into the shape of a tube with the rear end closed solid. This end of the tube is then "headed" as it is called, that is the cylindrical part is forced down upon the solid end until a double flange A A is formed, the outside diameter of the flange being about 1-16th inch larger than the diameter of the cylindrical part. The annular cavity inside the flange is filled with fulminate powder, so that a blow upon the outer edge of the flange will close the cavity, and thus cause the fulminate to explode and fire the gunpowder B.

The Central-fire cartridge is best illustrated by the Boxer Cartridge, shown double full size in the sections, Figs. 3 and 4, Plate 30. The case C of the cartridge is made of brass foil rolled into a cylinder and held together by cement, with a lapped joint, the foil making one and a quarter turn; this is covered outside with a wrapping of thin brown paper. The case contains the gunpowder B, with a layer of cotton wool between the powder and the bullet D. The rear of the case is flanged over inwards, and is closed by two cups E made of thin brass, the inner one being twice the length of the outer; and a central hole is punched through the bottom of each cup to receive the cap chamber F, which resembles a hollow rivet with the front end solid. A flange is formed on the rear or open end of the cap chamber, which fits into a countersunk hole in the base disc A; the edge of this disc projects all round beyond the circumference of the cartridge case, so as to form the flange for retaining the case in the gun chamber when fired. In putting the cartridge together, the cap chamber is threaded through the base disc A and the two brass cups E, and a coil of paper pressed into the form of a thick washer is put inside the case C, surrounding the cap chamber F;

this washer or wad is subjected to a considerable pressure after the parts are put together, and afterwards the solid end of the cap chamber is bulged over or rivetted upon the paper wad; and a small centre hole is punched through the solid end, for the fire of the fulminate to pass to the gunpowder. The anvil J is then inserted into the cap chamber, and the detonating cap G in the rear closes up the open end of the chamber, the fulminate in the cap presenting itself towards the point of the anvil. A blow upon the cap by the firing pin drives it against the point of the anvil and explodes the fulminate; and the fire communicates through the cap chamber to the gunpowder, the anvil J being rectangular in section, as shown in Fig. 4, and thus leaving a clear passage on each side in the cap chamber.

The first machines to be described are for making the Mitford Bullet now used for the Boxer Cartridge, as shown at D in the longitudinal section of the cartridge, Fig. 3, Plate 30. The machine which performs the first operation is shown in Fig. 5, Plate 31. It consists of a heavy bed A A supported on two standards, with two horizontal slides fitted on the front face of the bed and at the opposite ends. The right-hand slide B is moved to and fro by the eccentric C shown dotted, which is supported in a large boss projecting from the back of the bed; and the left-hand slide is actuated by a cam supported in like manner. Both these are driven by pairs of bevil wheels on a shaft passing along the whole length of the machine at the back; on the end of this shaft is a spur wheel D, driven by a pinion on the main driving shaft E. In front of the left-hand slide is mounted a shaft F carrying the circular cutter plate G, which is a plain disc containing twenty holes equally spaced round its circumference. The plate is rotated through the distance of one hole at a time by means of the ratchet-wheel H on the shaft F, which is actuated by a paul worked by an eccentric on the bevil-wheel shaft at the back of the machine. The lead for forming the bullets having previously been drawn into rods of the required diameter, a coil of this drawn lead is placed upon a reel at the left-hand side of the machine; and the lead is drawn into the machine by the traversing gripping apparatus K, which pushes the end of the rod into one of the holes in the cutter plate G. The next rotation of the plate shears off the length required to form a bullet; and the successive lengths thus sheared being carried round in the holes in the plate are brought successively into line with a horizontal traversing punch I and fixed die, which are similar in general arrangement to those employed in the next machine to be described, as shown in Figs. 9 and 10, Plate 33. The punch is carried on the right-hand slide B, and pushes the blank out of the hole in the plate G into the die on the other side of the plate, where the punch then forms a bell-mouthed recess in the front end of the lead, while it is confined within the die. The bullet is thus moulded to the form shown in the full-size section, Fig. 6; the bell-mouthed recess being in preparation for the cylindrical hole in the front end of the bullet, which receives the wood plug I, Fig. 3. The bullet is then pushed back again out of the die into the hole in the circular plate G, the closed end of the die being moveable and carried upon the left-hand slide of the machine; and the next rotation of the plate brings the bullet opposite the pusher J carried on the slide B, by which it is pushed out of the plate into a delivering spout. The number of bullets produced by this machine in regular work is 60,000 per day of ten hours.

The partially moulded bullets are then taken to the machine shown in Figs. 7 to 12, Plates 32 to 34, which performs the second operation. This machine is of similar construction to the first; but instead of being supplied from the rod lead, the partially formed bullets from the first machine are here fed by hand into the holes of the rotating circular feed plate G, which contains twenty holes, as shown in Fig. 12. The bullets are put into the plate with the front or recessed end foremost, so that the bell-mouthed recess already formed faces the left-hand slide of the machine; and the rotation of the feed plate in the direction shown by the arrow brings each bullet successively into line with the horizontal traversing punch I and fixed die M, shown to a larger scale in the sectional plans, Figs. 9 and 10, Plate 33. The punch I carried by the right-hand slide B pushes the bullet out of the feed plate G into the die M, the closed end of which is made of the required curved shape for the front end of the bullet, so that by the pressure of the punch I the lead is closed around the fixed centre pin N, which serves as a core for the purpose and is adjusted by lock nuts to the proper length. The original bell-mouthed recess in the front end of the bullet is thus converted into a cylindrical hole for receiving the wood plug; and at the same time the punch I forms the conical recess in the rear of the bullet for receiving the clay plug H, Fig. 3. Round the outer end of the die M a ring of six small holes O O are made, Fig. 10, as a provision against any excess of lead in the die beyond the limit allowed for the weight of the bullet, since it is impossible in the previous operation to cut off with sufficient nicety from the lead rod the exact quantity of metal for the bullet; any surplus therefore exudes through the small holes O O in the die, whereby the bullet is moulded with great accuracy to the exact size and weight required. The fixed centre pin N in the die lies within a hollow sliding rod L, Fig. 10, carried upon the left-hand slide P, Fig. 9; and when the punch I retires on the completion of the bullet, the rod L advances and pushes the bullet out of the die M, back into the feed plate G, by which it is then carried forwards, and afterwards discharged by the pusher J, as shown in Fig. 11. The number of bullets turned out by this machine in regular work is 33,000 per day of ten hours; Fig. 8 shows a full-size section of the bullet as delivered from the machine.

The next operation consists in Canneluring the bullet, or forming four grooves round the cylindrical part of the bullet to hold the lubricating material, as shown in Fig. 3. The Canneluring Machine is shown in Figs. 13 and 14, Plate 35, and consists of a horizontal circular plate A carried on a shaft B, and driven in the direction shown by the arrow in Fig. 13; the plate has a steel rim, the outer edge of which is turned to the exact profile of the grooved bullet. A segment C extending about one fourth of the circumference of the plate A is bolted to the table of the machine, and has its inner edge also turned to the profile of the grooved bullet. The bullets are fed by hand into a spout D and pressed forwards to the bite between the plate and the segment, whence they are rolled round between the two grooved surfaces, which thus form the cannelures or grooves upon them. The finished bullet is shown full size in Fig. 15, and the number of bullets delivered by the canneluring machine in regular work is 50,000 per day of ten hours. The cylindrical wood plugs in the front end of the bullets are inserted by hand before the canneluring is done, so as to "spin" the lead slightly over the rounded extremity of the wood plug in passing through the canneluring machine; this smoothes the point of the bullet and prevents the plug from falling out. As the clay plugs are not inserted till after the canneluring, the conical hole in the rear of the bullet becomes somewhat contracted in passing through the canneluring machine; but this is provided for by the hole being made proportionately larger in the first instance by the previous bullet-moulding machine.

The machine for making the cylindrical Wood Plugs, which are inserted in the front end of the bullets at I, Fig. 3, is shown in Figs. 16 to 19, Plates 36 and 37. The strip of prepared wood A of square section is carried in the rocking frame B in front of the machine, which is moved inwards and outwards by the cam C. The rotating cutter D, shown full size in Figs. 18 and 19, is carried in a headstock which is moved to and fro by the cam E and lever F; and when the wood rod A is brought into line with the cutter spindle by the rocking frame B, the cutter advances, and cuts the end of the square rod to a cylindrical shape, as shown in Figs. 18 and 20; the central shaper J, Fig. 18, at the same time rounds off the extremity of the rod to the proper curve corresponding with the profile of the front end of the bullet. The cutter then retires; and the rocking frame B being moved inwards by the cam C brings the cylindrical part of the wood rod in contact with the circular saw G, which cuts off the plug to the required length, and it falls into a drawer beneath. The wood rod A is held in a sliding gripper H, having a paul that catches in the feeding rack K, the teeth of which are spaced to the exact length of the wood plugs; and when the rocking frame B is pushed outwards by the cam C, the rack K is advanced the space of one tooth by means of a projecting stud underneath the rack, bearing against the inclined plane L, shown dotted in Fig. 17, which is attached to the table of the machine. The wood rod is thus fed forwards towards the cutter to the required length for the next plug; and when the rocking frame B next moves inwards towards the circular saw, the feed rack K is pushed backwards by the spiral spring N, so that the paul on the gripper H drops into the next tooth of the rack. The cutter spindle D and circular saw G are each driven by belts from the main driving shaft M, from which the cam shaft is driven by gearing O. The wood plugs are turned out by the machine at the rate of 15,000 per day of ten hours in regular work; and are inserted by hand into the front end of the bullets previous to the canneluring. The wood used for making the plugs is sycamore or beech; and the wood rods are soaked in cold-drawn linseed oil, chiefly in order to make them cut more easily.

The Clay-Plug Making Machine, shown in Figs. 21 to 25, Plates 38 to 40, moulds the clay plugs which are put into the conical recess H, Fig. 3, in the rear of the bullets, for the purpose of expanding this part of the bullet at the moment of firing, so as to force the lead into the grooves of the rifle barrel. The clay plugs are made from dry clay previously ground to a fine powder, which is compressed to the required shape in a mould by means of the vertical pressing slide A, Fig. 21; a heavy pressure is put upon the slide by the strong lever B, actuated by the cam C on the main cam shaft D. The cam is faced with steel at the part where the greatest pressure takes place; and works against an adjustable hinged flap, also faced with hardened steel, on the underside of the lever B. The bottom of the pressing slide A has a round head carrying fifty steel pins, as shown to a larger scale in Fig. 25, which compress the powdered clay in a corresponding number of moulds. Five sets of these moulds are let into a circular rotating table E, Fig. 23, which is mounted in the front of the machine, as shown in Fig. 21; and each set of moulds in succession is brought round under the pressing slide A by the intermittent rotation of the table, which is turned by means of the ratchet wheel F, Fig. 22, actuated from the cam shaft D. The bottoms of the fifty moulds in each set are closed by a corresponding number of steel pistons, the lower ends of which rest upon the circular block G, Figs. 24 and 25; this block is itself a piston fitting into the recess in the moulding table, and when brought round under the pressing slide A it rests upon the large vertical screw K carried in the frame of the machine, so that the pressure put upon the moulds by the slide A is borne by the screw K, instead of coming upon the moulding table E. In order to land each mould in succession upon the top of the screw K, the moulding table is lifted slightly at each time of turning by means of a spiral incline or crown ratchet-face I, Fig. 21, fixed to the centre spindle on the underside of the table; this incline raises the table $\frac{1}{4}$ inch, which gives the bottom of the mould 1-8th inch clearance above the top of the screw, and as soon as the mould is brought over the screw the table drops again $\frac{1}{4}$ inch, leaving the bottom of the mould resting solely upon the screw. The prepared clay for making the plugs is supplied from the brass hopper L through the pipe M, Fig. 24, which is closed by a flap valve at the bottom; a tappet J, Fig. 25, fixed on the pressing slide A, catches the valve lever N in each upstroke of the slide, and opens the valve, allowing a sufficient quantity of the clay for one set of fifty plugs to fall into the feed box P, in which it is distributed uniformly by the revolving arms Q. The bottom of the feed box is closed by two plates, perforated with fifty holes each, between which is a sliding plate R, also containing fifty holes, and worked by a cam on the main cam shaft. The holes in the bottom plate correspond exactly with the moulds in the moulding table, while those in the top plate are all set back a certain distance so as not to be opposite the holes in the bottom plate; and the sliding plate R is made of such a thickness as to measure off in each hole the exact quantity of clay required for each mould. The clay falls first out of the feed box into the measuring plate, and the plate being then moved forwards by the cam shuts off the communication with the upper holes, and allows the charge to drop through the lower holes into the moulds beneath, as shown in Fig. 24. The charged moulds are then brought round under the pressing slide A and subjected to the pressure; after which the next stroke of the machine and rotation of the cam shaft lifts up the block G supporting the steel pistons in the bottom of the moulds, Fig. 24, and pushes out the newly moulded plugs to a level with the surface of the moulding table E; this is done by means of the vertical plunger T, worked by the levers S S, Fig. 21, which are actuated by a face cam on the outer end of the cam shaft D. The swivelling arm U, Fig. 23, actuated by another cam W, then sweeps the plugs off the table E; and the same lever that works the swivelling arm withdraws at the same time the locking bolt V, which is provided for stopping the table dead after each turn and for holding it perfectly steady during the time that the clay is being compressed in the moulds under the pressing slide. A self-acting oiling apparatus is mounted over the moulding table at X, Fig. 21, so as to oil each set of moulds by a corresponding set of fifty vertical plugs, which are passed down into the holes as they come under, the plugs being covered with cloth kept moistened with oil. The machine moulds the plugs at the rate of 150,000 per day of ten hours, each revolution of the cam shaft producing 50 plugs, as shown full size in Fig. 26; the plugs are subsequently baked in an ordinary oven.

The next machine, shown in Figs. 27 to 33, Plates 41 to 43, is for Warming the bullet and Pressing in the conical clay plug H, Fig. 3, in the rear of the bullet. The object of heating the bullet is to expand it slightly, and thus fix the clay plug more firmly by the contraction of the bullet in cooling. The heating is effected by means of a horizontal steam wheel A, driven at the rate of rather less than one revolution per minute by a worm upon the cam shaft B, and supplied with steam through two of its hollow arms, the other two serving as waste pipes for the escape of the condensed water. The wheel has eighty brass cups fitted into its upper face, as shown in the plan, Fig. 27, into which the bullets are inserted by hand with the rear end uppermost. The bullets are fed in on the right-hand side of the machine at C, Fig. 27, the wheel revolving in the direction of the arrow, and by the time they reach the opposite side of the machine at D another attendant inserts the clay plug; after which they are removed from the wheel by hand and inserted into the holes in the circular feed plate G. This plate, containing twenty holes, Fig. 29, is rotated one hole at a time by a ratchet wheel and paul actuated by an eccentric E on the end of the cam shaft B; and it brings each bullet in succession into line with the two horizontal plungers I and J, Fig. 30, as shown to a larger scale in Fig. 31, Plate 43. These plungers are worked to and fro by levers actuated by the cams K and L on the shaft B, Fig. 27; the right-hand plunger I pushes the bullet out of the feed plate G into the fixed die M, which is bored out to the exact diameter of the rifle barrel, and acts as a gauge, preventing the bullet from being expanded by the pressing in of the conical clay plug. The left-hand plunger J advancing at the same time, as shown in Fig. 32, holds up the bullet against the plunger I with a definite amount of resistance, by means of the bell-crank lever F weighted by the spiral spring N, Fig. 30; the clay plug is thus pressed home into the rear of the bullet with a uniform pressure which cannot exceed the limit determined by the spiral spring. The left-hand plunger J, the head of which is recessed to receive the front end of the bullet, is now suddenly withdrawn by its cam, as shown in Fig. 33, and the bullet being pushed out of the gauge M by the plunger I falls into the delivering spout P, a small striker-off O being provided to ensure its falling clear. A full-size section of the finished bullet is shown in Fig. 28, and the number delivered by the machine is 40,000 per day of ten hours.

The foregoing machines, shown in Plates 31 to 43, complete the series of operations required for the production of the Bullets; and the next machines to be described are those for the manufacture of the several parts composing the Cases of the cartridges.

The Base-Disc Punching Machine, shown in Figs. 34 to 36, Plates 44 and 45, is for the purpose of making the base-disc A, Fig. 3, Plate 30, which closes the rear end of the cartridge, and forms the projecting flange all round for withdrawing the empty cartridge case from the rifle chamber after firing. Four of these base discs, one of which is shown full size in Fig. 37, are punched simultaneously at each stroke of the machine, out of a long thin strip of iron B B, Figs. 35 and 36, by the four hollow punches C carried on the left-hand slide D, which is set at an inclination, so as to punch the four discs diagonally out of the iron strip B, as seen in Fig. 35. Each punch works into a fixed bolster E, within which is a smaller punch F carried by the right-hand slide G; and as soon as the disc is punched out of the strip B, Fig. 36, the smaller punch F advances and punches out the centre hole in the disc, the hollow punch C serving as the bolster to the smaller punch F. As the two punches recede from each other, the smaller one carries back the disc with it, until it is stripped off by coming against the bush H through which the punch F works. A vertical plunger I, actuated by the cam K, then pushes the disc down, and it is discharged by the delivery spout L. The centre burrs punched out of the discs are discharged through the interior of the hollow punches C into the spout M. The iron strip B out of which the discs are punched is ·05 inch thick, and is traversed through the machine by the two pairs of feeding rollers N N, Fig. 35, each pair being driven with the required intermittent motion by means of a ratchet wheel and paul worked from the eccentric P. The machine makes 85 strokes per minute, and produces an average number of 136,000 base discs per day of ten hours.

The Base-Disc Countersinking Machine, shown in Figs. 38 and 39, Plates 46 and 47, is for the purpose of countersinking the centre hole in each disc, as shown full size in Fig. 40. The discs are fed by hand into the holes in the horizontal circular feeding table B containing twenty holes, by which they are carried round and brought successively underneath the countersink drill I; the drill spindle is driven by a strap from the vertical shaft C geared with the main driving shaft D. The drill spindle is mounted in a vertical slide E, which has a short vertical movement imparted to it from the eccentric F through the bell-crank lever G, so as to bring the drill down upon each disc successively coming under it. At the same time the hollow bolster J, carried in a lower vertical slide, is raised by means of the cam H and lever K, and presses the disc up against a small fixed stop, placed level with the upper side of the feed table B; the disc is thus gripped firmly and held secure from turning during the time that the drill is making the countersink. At the next move of the table B a plunger carried on the upper slide E pushes the countersunk disc down through the hole in the table, and it is discharged through a delivery spout. The feed table B is rotated by the ratchet-wheel and paul L, Fig. 38, actuated by the lever M and grooved cam N, Fig. 39; and the table is steadied in each stationary position by the weighted catch P fitting into notches in the circumference of the table. The machine countersinks the discs at the average rate of 24,000 per day of ten hours in regular work.

The Base-Cup Making Machine, shown in Figs. 41 to 45, Plates 48 to 50, is for the purpose of making the deeper of the two base-cups E, Fig. 3, which with the base-disc close the rear end of the cartridge. This machine is similar in general arrangement to the base-disc punching machine already described, and punches four circular discs simultaneously out of the thin strip of brass B by means of the four hollow punches C carried in the left-hand diagonal slide D, which is driven by the cam R, Fig. 44. The fixed bolsters E, Fig. 45, against which the punches C work, contain each a sliding socket S, which is pressed forwards against the punch C by a strong spiral spring H, set up by the hollow tail-screw T; so that the flat disc of brass punched out of the strip B is gripped tight all round the circumference between the punch C and the socket S. Whilst the disc is thus held during the dwell or stationary part of the cam R, the right-hand slide G advances the mandril F within the hollow socket S; the end of the mandril has its edge slightly rounded, and presses the disc into the hole in the hollow punch C, the aperture of which is made slightly bell-mouthed, so that the flat disc may be gradually drawn into the shape of a cup as it passes forwards into the cylindrical part of the hole. The finished cups are pushed forwards through the hollow punch by each successive cup as it is formed, and are discharged through the delivery spout M, Fig. 41. The machine shown in the drawings produces the deeper of the two base cups, as shown full size in Fig. 43; and the shallow base cup, which fits outside the deep one, is made by another machine of exactly similar construction, the only difference being in the sizes of the punches, &c. The inner cups are made of very thin metal, the brass strips out of which they are punched being only ·005 inch thick; but the outer cups are rather stronger, being made out of brass strips ·007 inch thick. Each base-cup machine is driven at 60 strokes per minute, making four cups at each stroke, and produces on the average 136,000 base cups per day of ten hours. The outer cup is made to be rather a tight fit upon the inner, and is pressed over it by hand;

after which, by means of the small Hand Lever Press shown in Figs. 46 and 47, Plate 51, a centre hole is punched in the base of each pair of cups, to receive the cap chamber F, Fig. 3; the punching is done at the rate of 12,000 per day of ten hours.

The Cap-Chamber Punching Machine, shown in Figs. 48 to 53, Plates 52 to 54, punches flat circular discs out of a long strip of brass, and then bulges each into the shape of a cylindrical cup, for the purpose of forming the cap chamber F in the rear of the cartridge, Fig. 3. This machine is very similar to the one already described for making the base cups, the principal difference being that the cap chambers are of smaller dimensions than the base cups, and consequently require less power for making them. The slides carrying the four pairs of hollow punches and mandrils are here placed horizontal, while the strip of brass B is fed through the machine at an inclination, as shown in Fig. 49. The shape of the bell-mouthed aperture in the hollow punch, and the rounded end of the mandril, are shown full size in Figs. 51 and 52; but as the thickness of the brass strip is ·02 inch, and the length of the finished cap chamber is about twice as great as its diameter, it is not attempted to produce the full length of cup out of the original flat disc at a single operation; the cap chamber is therefore made by this machine of the shape shown full size in Fig. 50, and afterwards undergoes a further drawing process in the machine next to be described. The cap-chamber punching machine is driven at 90 strokes per minute, and produces in regular work the average number of 144,000 cap chambers per day of ten hours.

The Cap-Chamber Drawing Machine, shown in Figs. 54 to 56, Plates 55 and 56, is for drawing out or elongating the cap chambers delivered from the preceding machine. The vertical slide A, worked up and down by a crank and connecting-rod from the shaft B, carries at the bottom a pair of rounded mandrils or punches C working into the very taper bolsters D, as shown full size in Fig. 56. A horizontal slide J underneath the punches C is moved backwards and forwards by the weight E and the face cam F on the crank shaft B; this slide carries two spring grippers, having recesses to receive the cups, which are fed by hand into two bell-mouthed holes in a tray H fixed in front of the punches. The sliding grippers carry a pair of the cups underneath the punches, which then descend and force the cups through the taper bolsters, thus elongating them by a drawing action. The cups are stripped off the punches in the up stroke, and the grippers at the same time return and bring up a fresh pair of cups for the punches. The machine makes 55 strokes per minute, delivering 50,000 cups per day of ten hours in regular work. The cups or cap chambers delivered from this machine, as shown full size in Fig. 57, are then annealed, and afterwards subjected to a second drawing process in a similar machine, by which they are finally elongated to the required extent.

The Cap-Chamber Trimming Machine, shown in Figs. 58 to 61, Plates 57 and 58, is for the purpose of trimming off to the exact length the open end of the cap chamber after the final drawing process. The cups to be trimmed are fed by hand into the holes in the circular feeding plate A containing fifteen holes, by which they are successively brought round into line with the horizontal sliding stud B and revolving chuck C. The slide D carrying the stud B is worked to and fro by the eccentric E, driven by belt and gearing from the main driving shaft F; and the stud entering the cap chamber pushes it into the gripping chuck C, as shown full size in the sectional plan, Fig. 61. The chuck is driven by a belt G from the driving shaft F, and runs at 5760 revolutions per minute, carrying the cap chamber with it. The trimming knife or cutter J, mounted on an oblique slide K, is then moved forwards by a cam on the back end of the shaft of the eccentric E, and trims the outer end of the cap chamber to the exact length required. The slide K is placed at an inclination of 45° to the axis of the chuck, as shown in the plan, Fig. 60, so as to cut the edge of the cap chamber with an internal bevil at that angle, as shown full size in Fig. 59, for the purpose of facilitating the flanging of the edge in the next process. When the trimming is completed, the cutter J and stud B are withdrawn; and the cap chamber being pushed out of the chuck C by the plunger L, sliding within the hollow spindle of the chuck, falls into a box beneath. The plunger L is attached to the slide D by the rod M, Fig. 58, so that the stud B is withdrawn clear out of the cap chamber, before the plunger L begins to push the cap chamber out of the chuck C. The circular feeding plate A is rotated one hole at a time by means of the paul and ratchet-wheel N, worked from the cam P, Fig. 60, on the front end of the shaft of the eccentric. The machine trims the cap chambers at the rate of 30,000 per day of ten hours in regular work.

The Cap-Chamber Flanging Machine, shown in Figs. 62 to 65, Plates 59 and 60, completes the cap chambers by "hatting" them or flanging the edge over outwards, forming the flanged rim which fits into the countersink in the base disc A, Fig. 3. The pair of flanging punches JJ, Fig. 64, carried in the vertical slide B, press the cap chambers into the fixed dies C C underneath; and the open end of the cap chamber projecting above the top edge of the die is flanged over outwards all round by the punch, as shown full size in Figs. 63 and 65. The flanging is facilitated by the internal bevil given to the edge of the cap chamber in the previous trimming process; and the shoulder of the punch J, Fig. 65, is rounded out to the shape of the required flange, while the edge of the die C is left square, as shown, without any rounding off. The bottom of the die has a small hole through it, which is closed by the vertical plunger I resting by a collar upon a fixed stop D below, Figs. 62 and 64; the top of the plunger is slightly hollowed out, so as to complete the bottom of the die to the correct shape for receiving the cap chamber, as shown in Fig. 65. When the punch J rises after flanging the rim of the cap chamber, the plunger I is lifted by the slide B through the lever E, and raises the flanged cap chamber to the level of the top of the die, as shown dotted in Fig. 65. The pair of finished cap chambers are then swept off sideways, right and left, into the receptacles F F, Fig. 64, by the two horizontal arms G, which are carried on the bottom of the two vertical shafts H and actuated by the face cam K, Fig. 62. The slide B carrying the punches J is worked by a crank on the extremity of the cam shaft. The cap chambers to be flanged are fed into the machine by hand through a pair of holes in the feeding tray L, and are carried forwards to the dies by spring grippers on the sliding bar M, which is worked by the second cam N, exactly the same as in the cap-chamber drawing machine previously described. The flanging of the cap chambers is performed by the machine at the rate of 44,000 per day of ten hours in regular work.

The Paper-Wad Making Machine, shown in Figs. 66 to 69, Plates 61 and 62, produces the paper wads, which are pressed into the bottom of the cartridges, Fig. 3, for the purpose of holding the various parts together. The wads are made out of long narrow strips of paper, wound in a coil upon a small revolving mandril A, Fig. 66; the width of the strips is equal to the thickness of the wad, and their length such that each strip makes a complete cylindrical wad of the required diameter, as shown full size in Fig. 67. The mandril A has a slit in it, into which the end of the paper strip is inserted; and the mandril being then made to revolve, winds up a coil of paper upon itself, as shown in Fig. 68, the paper strip being guided upon the coil by hand; the outer end of the paper is first pasted to prevent the wad uncoiling when finished. Each successive layer is pressed solid upon the previous one by the constant upward pressure of the pressing roller B, which is carried upon the top of the rod C, and held up against the paper coil by the india-rubber spring D. The mandril A is fixed in the front end of the spindle E, and the back end of this spindle carries an internal pulley F, within which runs a friction pulley G covered with hard leather, and driven by a belt from the main driving shaft H of the machine. The spindle of the friction pulley G is mounted in a rocking headstock J, connected by the rod K with the treadle L; and a spiral spring M underneath the treadle holds the headstock J in the central position, so that the friction pulley G is not in contact with the internal pulley F on the mandril spindle. For winding the wads, the friction pulley G is pressed against the internal pulley F by the treadle L. When the coil is completed, the pressing roller B is lowered by the second treadle N; and the same movement withdraws the mandril A by means of the double bell-crank lever P, the lower ends of which pass through two slots in the headstock of the mandril spindle E, and work in an annular groove in the spindle itself, Fig. 66; the newly wound wad is thus stripped off the mandril. The average number of wads made by the machine in regular work is 5,500 per day of ten hours.

The Paper-Wad Pressing Machine, shown in Figs. 70 to 74, Plates 63 to 65, is for the purpose of subjecting the paper wads to a severe pressure, so as to consolidate them throughout and compress them each to exactly the same thickness. The wads delivered from the preceding machine are fed by hand into the sixteen holes in the horizontal circular feed plate A, which brings each wad in succession under the pressing punch B, Fig. 70, carried in the vertical slide C, which is driven by a connecting-rod from the crank shaft D. The descent of the punch pushes the wad out of the feed plate A into the die E underneath, as shown full size in the vertical section, Fig. 74; and by the pressure of the punch the wad is compressed while in the die, and reduced to the exact thickness required, which is determined by the adjustment of the length of the punch. The hole in the centre of the wad fits upon the pin or mandril I, fixed in the centre of the die, which preserves the full size of the hole during the pressing. The bottom of the die is closed by a tubular slide G carried upon the crosshead H, Fig. 71; and under the pressure of the punch this slide is supported by a collar resting upon the bracket K cast on the frame of the machine, Fig. 70. In the ascent of the punch after pressing the wad, the pair of side rods L L, Fig. 71, from the vertical slide C to the crosshead H, raise the tubular slide G, which pushes the finished wad out of the die E back into the feed plate A; at the next stroke of the machine the wad is discharged from the feed plate by the stud N carried on the slide C, Fig. 71. The rotation of the feed plate A is effected by the star wheel M, Figs. 72 and 73, driven by gearing from the crank shaft D. The machine makes 75 strokes per minute; and the finished wads, one of which is shown full size in Fig. 75, are delivered at the rate of 30,000 per day of ten hours in regular work.

The next operation consists in Putting together by hand the several parts forming the body of the cartridge, and fixing them partially by means of the Hand Lever Press shown in Figs. 76 and 77, Plate 66, previous to the final compression given by the fixing machine shown in Figs. 81 to 84, Plates 67 to 69. The paper wad is put in the rear or closed end of the cartridge case, which is then covered by the two base cups and the base disc; and the cap chamber being inserted through the centre hole, all the parts are then pressed home upon one another in the hand lever press, Figs. 76 and 77, which has a horizontal sliding plunger A, working against a fixed bolster B, and moved by the hand lever C. The face of the plunger is recessed, so as to bear upon the base disc of the cartridge all round the circumference only; and in the centre of the plunger is a small projecting stud or mandril, fitting exactly inside the cap chamber, which is thereby pressed in through the centre hole in the paper wad; and the bolster B is made hollow, with a centre hole of the same diameter as that in the wad. With this press the cartridge bodies are put together at the rate of 3,000 per day of ten hours in regular work.

The Fixing Machine, shown in Figs. 81 to 84, Plates 67 to 69, completes the operation of fixing the body of the cartridge securely together, by subjecting the paper wad to a heavy pressure, so as to make it fit tight round the cap chamber and in the end of the cartridge case, and fix the cylindrical cartridge case securely in the base cups. The cartridge bodies already partially fixed are fed by hand into the notches in the circumference of the circular feed table A, whereby they are brought round successively under the pressing plunger B carried in the vertical slide C, which is driven by a connecting-rod from the crank shaft D. The plunger is made hollow, with the bottom face recessed, as shown full size in Fig. 84, so that it presses first all round the circumference of the paper wad K, closing it in tight upon the cap chamber F, and bulging it upwards in the centre round the cap chamber, as shown in Fig. 84. In order to prevent the cartridge case and base cups from being bulged outwards by the pressure of the plunger upon the paper wad, the semicircular notches in the feed table A are shaped exactly to the external profile of the cartridges; and as each cartridge is brought round under the plunger, a corresponding semicircular swage or die on the end of the horizontal slide E is advanced by means of the face cam G on the crank shaft D. The cartridge is thus securely embraced all round in a closely fitting die during the time that it is under the pressure of the plunger. The horizontal pressure of the slide E against the feed table A is received by a brass bearing on the opposite side of the feed table, set up by the screw H. The feed table is rotated by the star wheel L, Fig. 81; and the cartridges after being fixed are discharged from it by the curved finger J, Fig. 83, which lies in the groove M, Fig. 84, turned in the circumference of the feed table. The machine makes 55 strokes per minute, and turns out the cartridges at the rate of 30,000 per day of ten hours in regular work.

The Cap-Chamber Rivetting and Piercing Machine, shown in Figs. 85 to 90, Plates 70 and 71, rivets the closed end of the cap chamber over the paper wad, and then pierces the firing hole through the cap chamber. The cartridge cases are fed by hand, rear end upmost, upon the upright studs I I on the circular feed table A, by which they are brought round in succession under the rivetting punch B, Figs. 88 and 89, carried in the vertical slide C. The punch B is made with a projecting pin at the bottom, as shown full size in Fig. 89, exactly fitting the cap chamber F, so as to prevent the cap chamber from buckling inwards under the pressure of the punch in the rivetting; and the pressure of the punch B is distributed over the whole area of the base disc of the cartridge by the small plate D, supported by two bolts with india-rubber washers E, which yield to the pressure of the punch. The top of each stud I is recessed to the required shape, and serves as the die in which the closed end of the cap chamber is rivetted over the paper wad by the pressure of the punch; by this means the paper wad, cartridge case, base cups, and base disc, are all held securely together by the cap chamber in the centre, the open end of the cap chamber being countersunk into the base disc, while the closed end is rivetted over the paper wad. A projecting stud G fixed on the side of the slide C, Fig. 88, presses each cartridge case down home upon its die before it comes under the rivetting punch B. After the rivetting, the next turn of the feed table A brings the cartridge under the piercing needle J, shown full size in Fig. 90, which is also carried in the vertical slide C; the stud I is made hollow in the centre to receive the point of the needle, Fig. 90, which pierces the small hole through the rivetted end of the cap chamber, for the fire from the fulminate in the cap chamber to communicate with the gunpowder in the cartridge case. Full-size sections of the cartridge case are shown in Figs. 86 and 87, before the rivetting, and after rivetting and piercing. The cartridges are removed by hand from the studs on the feed table; and the machine makes 65 strokes per minute, delivering the cartridges at the rate of 37,500 per day of ten hours in regular work.

The cartridge case is then filled with the required charge of gunpowder, covered with a small wad of cotton wool in front, as shown in Fig. 3; after which the bullet is inserted in the open end of the cartridge case, and secured by indenting the case all round into the lowest groove or cannelure in the bullet. This is done by the Choking Apparatus shown in Figs. 78 to 80, Plate 66, having a pair of semicircular dies, closed upon the cartridge by a hand lever; two strokes of the press are given for fixing the bullet, the cartridge being turned a quarter round between the strokes, so as to secure the bullet completely all round. The operation is performed at the rate of 5,500 cartridges per day of ten hours in regular work with a single choking press.

The Capping Machine, shown in Figs. 91 to 94, Plates 72 and 73, is the last of the machines employed in the manufacture of the cartridges, and performs the final operation of inserting and pushing home the detonating cap G and the anvil J, Fig. 3, in the cap chamber F. As this has to be done after the cartridge is loaded with the powder and ball and the cap charged with fulminate, it is necessarily a dangerous process; until recently it was performed by hand, but in consequence of a fatal accident the machine shown in the drawings was invented, which to a very great extent obviates all risk. The machine has two circular feeding tables B and C, Figs. 91 and 92, geared together by equal spur wheels. The larger table B has fifteen recesses in its circumference to receive the charged cartridges, which are fed upright into the recesses with the base downwards; the rim of this table projects over that of the smaller table C, which contains fifteen holes to receive the detonating caps and anvils fed in by hand. By the rotation of the two feed tables the cap is brought round exactly underneath the cartridge, on the centre line of the two tables, as shown full size in Fig. 94; and the vertical plunger I then pushes the cap and anvil up into the cap chamber F of the cartridge. The plunger I is carried in a vertical slide D actuated by a crank on the shaft of the spur wheel E, Fig. 92, which is driven by a pinion on the main driving shaft H, worked by the treadle K. The cartridge is held down against the upward pressure of the ascending plunger I by the shoulder on the table B and the fixed crossbar L, projecting over the edge of the base disc A, Fig. 94. Immediately over the cartridge where the cap is being inserted is fixed a vertical brass tube M, about 3 inches diameter; so that in case of the cartridge exploding, the bullet and the gas from the explosion are discharged up the tube, thus protecting the attendants from danger. The finished cartridges are pushed out of the feed table B by the plunger N, Fig. 93, carried on the same vertical slide D as the capping plunger I. The two feed tables are rotated by the ratchet-wheel P, which is worked from a cam formed in the side of the spur wheel E. By this machine the capping of the cartridges is done at the rate of 20,000 per day of ten hours in regular work.

The entire set of twenty-one machines that have now been described in their regular order of succession are all employed in the manufacture of each cartridge; and the several operations required are performed by the machines at the very rapid rates of from 3,000 to 150,000 per day, as named for each machine.

Mr. **Greenwood** exhibited a series of separate specimens of the several parts forming the complete cartridge, in illustration of the successive stages of the manufacture.

Mr. W. E. **Newton** remarked that the great variety of machines described in the paper just read displayed a large amount of ingenuity in adapting their construction to the numerous operations required to be performed in the manufacture of the cartridges; and he was sure the meeting must congratulate the author of the paper upon the mechanical ability which had been manifested in working out so difficult a problem with such thorough success. With regard to the relative advantages of the rim-fire and central-fire cartridges, the former had certainly the merit of greater simplicity, as seen by a comparison of the two kinds of cartridge shown in the drawings. At the same time however he thought the rim-fire cartridge had some serious disadvantages, the principal of which was that the fulminate was placed within the groove which formed the flange round the rear end of the cartridge; and in the formation of this projecting flange out of the original cylindrical cartridge case, the metal became so much attenuated, that the rim itself was liable to be burst by the explosion of the fulminate in firing, and cause injury to the eyes in firing the rifle. Another objection was that it was necessary to fill the rim with fulminate all round the entire circumference, thereby using eight or ten times as much fulminate as was really needed to fire the gunpowder, and at the same time increasing the risk of bursting the rim itself and letting out a back-fire. In the plan of central-fire cartridge described in the paper he did not see what advantage was gained over the ordinary metallic cartridges, which were made so completely impervious to water that they might be kept under water for almost any length of time, and would yet be preserved perfectly dry and ready for firing at any moment. The cartridge case shown in the drawing however, not being perfectly water-tight, there would at any rate be great risk in putting it into water; and if it did accidentally get wet, the chances were certainly against its exploding. For although the cylindrical part of the case containing the gunpowder was made with a thin film of metallic coating underneath the external paper covering, it was not made sufficiently secure at the joints of the metal to exclude moisture. That construction might no doubt be a little lighter and less expensive in the manufacture, owing to the use of the thin brass foil, instead of the thicker metal case employed in the ordinary metallic cartridge; but he did not think this would counterbalance the great disadvantage of its not being perfectly waterproof. The objections felt to the use of metallic cartridges when breech-loaders were first generally adopted, from the idea that there was danger of the cartridges exploding by being knocked about before they were put into the gun, had proved altogether unfounded, as it had been shown that they might even be hammered under a sledge hammer without risk of exploding; and these cartridges had been used with very good results in the United States and other countries. In England it had been decided to convert the Snider rifle so as to adapt it for a central-fire cartridge; but he did not think that construction of breech-loader was good enough to be the one ultimately used in this country, and it could only be regarded as a temporary expedient. Other countries had experienced similar difficulties in arriving at a satisfactory construction of breech-loader, the Prussian needle-gun having been found extremely defective; while the French chassepot rifle, also a needle-gun, had proved very little better, although possessing some points of merit. The liability however of the needle-gun to miss fire frequently, on account of the long needle getting slightly bent, as explained in the paper, was a most serious objection, which unfortunately had not been recognised by the French military authorities until after a very large supply of these breech-loaders had been procured; and in consequence of this defect the chassepot gun he believed was now about to be abandoned.

Mr. GREENWOOD said he had not intended to enter at all into the question of which was the best cartridge, and he thought that was a very debatable subject; but his object had been simply to describe the machinery employed in the manufacture of the one particular construction of central-fire cartridge which was required to be produced in such large numbers, for the supply of the army of this country. With regard to the invention of the machinery for this purpose, he wished to mention that a large share of the merit of designing it was due to Mr. Davidson, of Woolwich Arsenal, who had been working at the subject for a great length of time; and it had only been step by step that they had succeeded in arriving at the present state of perfection in the manufacture of the cartridges.

The CHAIRMAN enquired what was the rate at which the cartridges were now being produced by the machinery described in the paper.

Mr. J. DAVIDSON replied that the cartridges were being produced at the rate of 1¼ millions per week in regular work at the manufactory in Woolwich Arsenal.

The CHAIRMAN enquired what had been the principal mechanical difficulties met with in designing the numerous machines employed for manufacturing the cartridges.

Mr. GREENWOOD said that the difficulties arose gradually during the experiments upon the successive constructions of cartridge that were tried before arriving at the one now adopted. The most serious difficulty had been to make the base or rear of the cartridge case sufficiently strong to resist the explosion of the powder; and it had been originally attempted to close it with only a single base cup, having an external projecting rim formed round the base by a process called "heading," like the hollow flange of the rim-fire cartridge, this rim being for the purpose of getting hold of the empty cartridge case for extracting it after firing. But it was soon found that this construction had the same defect which had been pointed out in reference to the rim-fire cartridge, the metal being made so much too thin at the angle by the stretching in flanging over that it was liable to be burst round the edge by the explosion. The two base cups, the deeper within the shallower one, were therefore adopted to strengthen the rear of the cartridge; and it was the production of these base cups in large quantities out of the very thin metal employed for the purpose which had been found one of the greatest of the mechanical difficulties to be overcome. The machine for making the cups had four hollow punches and bolsters for punching circular discs out of the flat sheet of thin metal; and a mandril working within the bolster then forced the disc through a bell-mouthed aperture in the hollow punch, so as to draw the flat disc into the shape of the cylindrical base-cup. In the first attempts to accomplish this, the edges of the cups were found to be puckered all round; and it was only after a great number of attempts had been made and several months spent in experimenting that it was ascertained that the puckering arose from the mandril and the hole inside the punch not being made with sufficient accuracy to work well together; but now that they were made perfectly accurate, the machine worked quite well, and no difficulty was experienced in making the cups without any puckering.

Mr. W. **Bouch** enquired whether the success was at all due to the use of any particular material for the metal cups or for the mandrils.

Mr. **Greenwood** replied that the absence of puckering did not depend upon the metal used for the cups, but upon making an exact fit between the mandril and the cylindrical hole in which the metal was drawn into a cup; and an error of 1-1000th inch in the diameter of either the mandril or the hole was enough to spoil the cups turned out. Each machine was made with four punches, for the purpose of producing the cups with the required rapidity, and there was no means of adjusting each pair of punches and bolsters separately; the great difficulty therefore lay, first in getting the slides fitted and bedded so accurately that they would work a considerable time without any perceptible wear: and then in boring out the holes to receive the punches, bolsters, and mandrils, with such perfect accuracy that when these several parts were each ground up to the standard gauge, and fitted into the holes in the slides, they would work together with complete truth, without any other adjustment. When this was once accomplished, the machine would continue afterwards to work with entire success. The mandrils were made of steel, and the machine was tried beforehand by setting it to punch the thinnest tin foil, such as was used for covering the necks of bottles; and if it was successful in forming perfect cups out of this, it was considered correct and fit for use for the manufacture of the cartridge base-cups; the thinnest paper was not considered to give a sufficiently severe test, and the tin foil was therefore used instead for testing the accuracy of the machine.

Mr. H. Chapman observed, in reference to the difficulty of making the base cups without puckering, that the metal capsules manufactured for containing moist colours were made without puckering, and he understood they were made by simply raising the disc of metal by the pressure of a punch in a shallow die, without the necessity of employing a die of the full depth of the capsule: for instance, a capsule 2 inches long could be made with a die of only $\frac{1}{4}$ inch depth.

Mr. Greenwood said he did not know exactly how those capsules were manufactured, but they were of much softer metal than the base cups, and he thought the brass used for the base cups would be found too hard to be drawn as much as would be necessary for making such capsules out of a single piece of metal without joint.

Mr. H. Chapman believed the manufacture of the capsules involved other points than the softness of the metal used, as he understood similar capsules had been made of steel by the same process.

Mr. Greenwood said he had heard of the steel capsules, and believed they were produced by successive processes of punching, in which case the expense of manufacture would be very great, and the production necessarily slow. In the manufacture of the base cups for the cartridges economy and rapidity of production had been specially kept in view; and they were turned out at the rate of 136,000 per day from a single machine having four punches.

The Chairman enquired whether copper would have been found preferable to brass for forming the base cups, so as to give greater strength to prevent the cartridge case from bursting at the rear in firing.

Mr. Greenwood said many cartridges had been made for the French government with copper base cups; but there was such a want of uniformity in the quality of the copper obtained for the purpose that it was found sometimes too hard and sometimes too soft for satisfactory working. It was therefore now preferred to make the cups of brass of definite composition, whereby a sufficient uniformity of quality was ensured for successfully working the very thin sheets of metal from which the cups were made.

The **Chairman** enquired what was the weight of the bullet in the cartridge, and what margin of weight was allowed for variations in the manufacture of the bullets.

Mr. **Greenwood** replied that the weight of lead in the bullet was required to be 530 grains, and the margin allowed for error was only 1½ grains above and below that amount, or 3 grains total variation. That constituted another of the difficulties which had been encountered in the manufacture by machinery, as the exact weight of lead required for the bullet could not be cut off from the original rod of lead within 2 grains at least above and below the required weight; care was therefore taken to cut off enough, and then in the final moulding of the bullet any small surplus was allowed to exude under the pressure through the six small holes made laterally round the outer end of the mould, which acted like safety valves. By this means the bullets were all finished to the required weight within the very small margin of variation allowed. The operation of punching the cylindrical hole in the front end of the bullet, which was itself to be shaped at that part to a parabolic profile, had been attended with much difficulty when it had at first been attempted to be done by a single process, because a cylindrical punch of the form of the finished hole soon became bent; for as the rod-lead had to be of smaller diameter than the die in which the bullet was moulded, in order that it might be fed easily into the cutter-plate and dies, it was not presented quite concentrically to the punch, but lay on the lower side of the die, leaving a space on the upper side until it was forced to fill the die by the pressure applied at the rear. There was thus more lead on the under side of the punch than on the upper side; and consequently when the pressure was applied to form the parabolic curve of the front end of the bullet, the excess of lead on the lower side of the cylindrical punch pushed the punch upwards and bent it. This difficulty had now been got over by the simple expedient of punching a bell-mouthed recess in the front end of the bullet in the first operation, while the profile of the bullet remained entirely cylindrical, the punch used for this purpose being made of a short stiff conical form, instead of the slender parallel form of the finished hole; and afterwards in the second process the front end of the bullet was closed in upon a cylindrical mandril of the form of the finished hole, so as to make the front hole cylindrical by the same operation which gave the parabolic shape to that end of the bullet, without putting a side strain upon the cylindrical mandril.

Mr. W. **Bouch** enquired what was the weight of the finished cartridge.

Mr. **Greenwood** replied that ten cartridges weighed 1 lb., the weight of the powder being 70 grains, the lead 530 grains, and the cartridge case &c. 100 grains.

Mr. W. E. **Newton** enquired whether the Boxer cartridge was applicable to the "magazine" or repeating rifle; and how many shots that rifle was capable of firing at one loading.

Mr. **Greenwood** replied that the repeating rifle would fire from seven to fourteen shots at one loading. The Swiss rifle would fire fourteen shots, and had its magazine under the barrel; but this made the gun clumsy to handle, as the weight of the cartridges was added to the weight of the barrel. The American rifle had the magazine in the butt part of the stock, and was consequently more convenient for handling; it contained only seven cartridges, but could be used as a single breech-loader, keeping the magazine full, with as much facility as any single breech-loader yet produced, whilst leaving the reserve in the stock to be fired at the rate of 28 shots per minute. The Boxer cartridge was not applicable to the repeating rifle on account of having a central fire, which rendered the cartridge dangerous in that rifle, because the front end of the bullet would be brought into contact with the percussion cap when the cartridges were placed end to end in the magazine; and a sudden shock, such as might be produced by careless loading or by letting the rifle fall, might explode a percussion cap and fire off the whole magazine. On this account no construction of central-fire cartridge was suitable for the repeating rifle.

Mr. W. E. **Newton** enquired whether any machinery had been constructed for making blank cartridges for the repeating rifle, to be used for rifle drill.

Mr. Greenwood said he had made machinery for that purpose, by which a number of blank cartridges for drill were manufactured; the bullet was made of pine wood, turned hollow, so that it blew to pieces at three or four yards from the muzzle of the gun, and a person could stand at a distance of five yards from the muzzle without any risk of being injured by the discharge.

The Chairman said he was sure they all felt greatly indebted to Mr. Greenwood for the amount of trouble he had taken in bringing the subject of the paper before the meeting in so elaborate a manner, and for the very valuable and extensive series of drawings, by which the whole of the machinery employed in the manufacture of the cartridges was so completely illustrated.

He proposed a vote of thanks to Mr. Greenwood for his paper which was passed.

The following paper was then read:—

ON THE APPLICATION OF MACHINERY TO COAL CUTTING.

BY MR. JOHN FERNIE, OF LEEDS.

The objects to be gained by the application of machinery to Coal Cutting are—firstly, the cheapening of the work; secondly, the saving of a large quantity of coal, which in the ordinary process of holing or undergoing by hand labour with the pick is broken up into slack and dust; thirdly, the removal of the danger attendant upon undergoing by hand labour; fourthly, the getting of a larger quantity of coal out of the pit with the same length of working faces opened; and fifthly, in the case of machines worked by compressed air, the collateral advantage of better ventilation and a cooler atmosphere in the mine, owing to the discharge of the compressed air after each stroke of the tool. The difficulties attending the application of machinery to work previously performed by hand are greatly increased in the case of coal-cutting machines, by their having to work at great depths below ground, and in the very confined passages of a mine.

In the present paper the writer proposes to describe two Coal-Cutting Machines driven by compressed air, one having a pick worked by a bell-crank lever, with an action like that of the ordinary pick used in hand work, and the other working a straight-action tool somewhat in the manner of a horizontal traversing slotting machine. Both these machines have now been successfully employed in regular work for a length of time at collieries in the neighbourhood of Leeds, where they may be seen at work by the Members at the present meeting.

The coal-cutting machine shown in Figs. 1, 2, and 3, Plates 74 and 75, which has been brought to its present state by Messrs. W.

and S. Firth of Leeds, is constructed for working a pick by means of a bell-crank lever, so as to give an action similar to that of the ordinary pick employed in hand work.

The pick A is fixed in a socket in one of the arms of the bell-crank lever B, the other arm of which is worked direct by the piston-rod of the horizontal cylinder C. The slide-valve D, Fig. 4, for the admission and discharge of the compressed air by which the machine is driven, is an ordinary slide, worked by a tappet roller E upon the piston-rod; the machine is thus self-acting as regards the strokes of the pick, which is started to work as soon as the compressed air is turned on by the stop-cock F in the supply pipe G. The machine is mounted upon four wheels running upon the ordinary rails of the colliery, and is advanced the requisite distance between each blow of the pick by a handwheel H connected by gearing with the hind pair of carrying wheels. The two pairs of wheels are coupled together, in order to render the full adhesion available for the forward motion of the machine; and by this means it is found that sufficient adhesion is obtained without the necessity of laying down a special rack-rail for the feed motion.

As the return of the pick after each blow is made by means of the self-acting tappet motion working the slide-valve, it is necessary that the tool should go to the full extent of its stroke at each blow, before it can be withdrawn again. The amount of feed between each blow has therefore to be regulated by the attendant, according to the hardness of the seam of coal in which the machine is cutting, so that the pick shall complete an entire cut at each blow. In the event however of the pick being advanced too far at any blow, so as to put too much work upon it and stop it before the stroke is completed, it is only necessary to draw the machine back again by means of the handwheel H, until the pick is released from the cut; the unfinished stroke is then completed, and the pick goes on working again the same as before the stoppage. In order to allow of altering the height at which the pick performs the holing in the coal, the socket K carrying the pick is made to slide vertically upon the shaft of the bell-crank lever B, the height of the socket being adjusted by the forked arm J controlled by the screwed rod and handle L.

One of these pick machines is now in regular work doing the whole of the undercutting in the West Yorkshire Coal and Iron Co.'s colliery at Tingley near Leeds, holing a seam of coal 3 ft. 8 ins. thick; and the compressed air for driving it is supplied by an air-compressing engine at the surface, with steam cylinder of 20 inches diameter and 3 feet stroke, working an air cylinder of 18 inches diameter and the same stroke, and compressing the air to about 50 lbs. per square inch pressure. The depth of the pit is 170 yards, and the air is conveyed down the shaft and along the mine in 2½ inch cast-iron pipes, with a 1¼ inch wrought-iron pipe laid up the bords to the working faces, and then a 1¼ inch flexible tube to the coal-cutting machine. Small air vessels are placed at intervals of 500 yards along the air main, for the purpose of maintaining the pressure of the air at the machine, when working at a considerable distance in the mine; the machine is worked at a distance of as much as a mile from the shaft.

In a trial recently made of this machine by the writer, it was found that a pick of 75 lbs. weight, cutting a groove to a depth of 24 inches in from the face, gave about 74 blows per minute. At this colliery the coal is got by the long-wall system of working, as shown in the plan, Fig. 5, Plate 77, in which the machine is indicated at M working along the straight face of 50 yards at one of the banks. The time occupied by the machine in undercutting a length of 56 feet was 25 minutes, including all stoppages for clearing the rubbish out of the hole and for backing the machine when the pick occasionally made an incomplete stroke. The machine was then run back to the starting point, and set to work again with a longer pick of 90 lbs. weight, completing the previous cut to the final depth of 3 ft. 9 ins. in from the face. With this pick the blows were about 60 per minute, and the half length of 28 feet was undercut in 17 minutes, including all stoppages. The time occupied in running the machine back, and changing the pick, was 16 minutes. The machine in this case was working at a distance of about a mile from the bottom of the shaft.

From this trial it appears that in undercutting to the depth of 24 inches in a single course, the work done by the machine was at the rate of about 30 square yards per hour; and in undercutting in two courses to the total depth of 3 ft. 9 ins., the work was done at the mean rate of about 15 square yards per hour, including the time required for running the machine back and changing the pick.

The width or height of the groove cut out by the pick is 2 inches at the inner extremity, widening out slightly towards the face of the coal. It is necessary to stop the machine at intervals, in order to clear out the rubbish left in the hole; and the rails in front of the machine have also to be cleared of the material thrown out by each return stroke of the pick. Two men are required to attend to the machine, one working the handwheel for the advance of the machine, and the other clearing away the stuff.

A good criterion of the actual rate of working that may be safely reckoned upon with this machine in regular practice is afforded by its performance upon an occasion when it was kept continuously at work for 24 hours consecutively, on 21st and 22nd of May last. During this time the machine was employed upon five different banks of coal successively, requiring accordingly to be shifted four times for the purpose. The average depth of holing was 3 ft. 6 ins., and the total length of work completed to that depth during the 24 hours amounted to 257 yards. This gives the practical rate of holing by the machine at rather more than 12 square yards per hour, including all stoppages for clearing the pick in working and for shifting the machine on the completion of each separate length of bank.

The other coal-cutting machine to be described, which is shown in Figs. 6, 7, and 8, Plates 78 to 80, is the invention of Mr. G. E. Donisthorpe of Leeds, and may be described as a horizontal traversing slotting machine, the work remaining stationary, while the machine traverses along the working face of the coal and cuts out a horizontal slot or groove along the bottom of the seam of coal or along a parting in the thickness of the seam itself.

The cutter bar A carrying the cutting tools is fixed upon the upper side of the working cylinder C, which moves horizontally forwards and backwards at each stroke, the piston and piston-rod remaining stationary. This arrangement has the advantage of economising space, and giving greater stiffness and a better attachment of the cutter bar; and the whole is guided steadily between the guides B B, by means of four sets of steel rollers D D attached to the cylinder and steadying it both vertically and laterally, as shown in the sectional plan of the cylinder, Fig. 9, Plate 81. The piston-rod E is made hollow, as shown in Figs. 9 and 11, having two passages communicating with the opposite sides of the piston; and the alternate admission and exhaustion of the compressed air is regulated by a cylindrical slide-valve F, Figs. 6 and 12, worked by the hand lever G. The ports in the piston are circular, and at each end of the cylinder a projecting plug J is fixed on the inside of the cover, opposite to the port, as shown in Figs. 9 and 10; this plug entering the port at the end of the stroke prevents the complete escape of the whole of the air in exhausting; and the air thus retained in the cylinder forms an air cushion at the end of the stroke, whereby the piston is prevented from striking the cylinder cover at either end. A subsidiary port I, Fig. 10, alongside the main port, and provided with a valve opening outwards, affords a passage for the admission of the compressed air at the commencement of the next stroke, until the main port is unstopped by the withdrawal of the plug J.

The working cylinder C is 6 inches diameter with 12 inches stroke; and the frame B in which it is carried is itself slung upon horizontal trunnions H, Fig. 7, in another frame K sliding vertically upon the pillars L L, which are fixed on the base-plate M of the machine; and by means of a screw N and worm-wheel, Fig. 6, the working cylinder can thus be raised or lowered bodily to any height at which the cutter is required to work. The trunnions and the curved slot H, Fig. 7, also allow of the cutter being adjusted by means of the handwheel and screw X to work at an inclination to the horizontal, between the limits shown by the two dotted positions in Fig. 7.

The cutter bar A, Figs. 7 and 8, is of cast steel, having six sockets for carrying the cutting tools. The tools are made of flat bar steel, with one-quarter twist in the shank, by which means the cuttings are thrown away from the face of the cut at each stroke of the bar A. The cutters are placed about 7 inches apart longitudinally along the length of the bar A, the average depth of the cut being about 3 ft. 4 ins. in from the face of the coal; and the length of stroke being 12 inches, the tool does no work during the first 5 inches of the stroke, but acquires a rapid motion whereby it strikes upon the coal with the percussive action of a blow, instead of cutting by a uniform steady pressure like an ordinary slotting tool. Previous to the adoption of this principle of working, the present pressure of air of 60 to 70 lbs. per square inch was found insufficient to work the machine; but with the percussive action now obtained this pressure is found completely effective, and the diameter of the working cylinder being 6 inches, the blow is given with a total force of 1700 lbs. or ¾ ton upon the tool. The cutters are stepped 2½ inches successively in advance of one another, as shown in the plan, Fig. 8, Plate 80; and the bar is fixed upon the working cylinder by a centre pin O and set screws P P, allowing it to be set obliquely in plan at an inclination to the line of the stroke, as shown by the dotted lines in Fig. 8. By this arrangement the inclination of the cutters to the work can be slightly increased or diminished, according as may be required by the quality of the coal, so as to obtain under all circumstances the most effective action of the cutters. The width of their cutting edges ranges from 1¾ inches in the cutter at the outer extremity of the bar to 3 inches in the cutter nearest the working cylinder; and the slot cut out by the machine is therefore of the slightly tapered form shown in Fig. 7, Plate 79.

The machine is mounted on four double-flanged wheels, Fig. 8, Plate 80, running on rails laid for the purpose. The rail on one side is a plain wrought-iron bar Q placed on edge; and the other rail R is made of two bars placed 2 inches apart, with a series of cross pins at 1½ inch pitch, forming an open rack-rail, into which gears a pinion S worked by a handwheel T, whereby the machine is advanced for each cut, the ordinary amount of feed being 1¼ inch per cut. As the advance is given by hand by the man working the machine, any number of strokes can be given by the tool before the machine is moved forwards, in case the coal is too hard for the cutters to accomplish the full depth of cut at a single blow. The traversing pinion S gearing into the rack rail is mounted in a slide on the base-plate M of the machine, whereby it can be raised out of gear with the rack when the machine has to be drawn away from one part of the mine to another.

The pressure of the air working the machine is also employed for steadying it against the blows of the tool, so as to ensure the full effect of the blow being expended upon the coal at each stroke; otherwise the tool would be liable to be bent or broken, and the work would be irregular. This is accomplished by means of two vertical cylinders U U, each 8½ inches diameter, the piston-rods of which stand up towards the roof of the mine, and are connected together at the top by a horizontal frame V carrying a grooved wheel at each end. A loose iron rail on a wood batten W is placed above the grooved wheels; and the compressed air being admitted on the underside of the pistons in the cylinders U, the rail is pressed up against the roof of the mine, as shown in Figs. 6 and 7. The total pressure exerted by the pair of cylinders U U amounts to 6800 lbs. or upwards of 3 tons, which is found amply sufficient to resist the blow of the tool. When the machine in its forward traverse has arrived at the end of the roof rail W, the pressure is shut off from the cylinders U, and the air is let out from them through cocks opened by hand, thus lowering the frame V as shown by the dotted lines in Fig. 6; the roof rail is then shifted forwards to the extent of its length, and the pressure being readmitted to the cylinders U, the machine is again ready for continuing its forward traverse as before. The pressure exerted against the roof being elastic allows the top rail to accommodate itself to any irregularities in the level of the roof.

The working of this coal-cutting machine having been witnessed recently by the writer at the West Riding Colliery of Messrs. Pope and Pearson, at Normanton near Leeds, it was observed that the number of strokes made by the tool was from 75 to 80 per minute, the pressure of air at the machine being from 65 to 70 lbs. per square inch at the time. The average depth of the cut during the time of observation was about 2 ft. 9 ins., as there was a clearance space of more than 1 foot left between the side of the machine and the face of the coal, the rails not having been laid close enough to the face of the coal. The width of the cut is about 2 inches at the inner end, widening to about 3 inches at the face of the coal; and as the cut was in this case being made in a parting of dirt of about the same thickness, no waste of coal was produced by cutting the groove. One man is required to work the machine, working the air valve F by the hand lever G, Fig. 6, and also giving the feed of the tool by the handwheel T advancing the machine; and from 3 to 5 strokes were given by the tool between each advance of the machine, for completing the cut to the full depth of the groove; about three turns were then given to the traversing handwheel, advancing the machine about 1¼ inch, after which the same number of strokes were again given with the tool. The cuttings are cleared out of the groove by a man following the machine with a narrow curved rake; and the height of the cutting tool in the machine is regulated occasionally, according to the slight variations in the level of the parting in which the groove is made, so as to keep the tool always working in the parting.

The width of the groove cut by this machine is shown in Fig. 7, the width at the face of the coal being not more than about 3¼ inches in holing to the full depth to which the machine can work. In undergoing by hand to the same depth, the size of the cut is as shown in Fig. 13, Plate 79, having a width of at least 13 inches at the face of the coal, making the whole size of the cut about three times that of the narrow groove excavated by the machine, which is shown by the dotted line in Fig. 13. Supposing the machine to be holing in the solid coal, the waste produced by the undergoing in a seam of 5 feet thickness, such as is being worked at the West Riding Colliery, would amount to only about 4 per cent., as compared with about 12 per cent. waste with hand work. An estimate of the absolute quantity of waste made by hand work in good seams of coal amounts to as much as 12 per cent., the whole of which is rendered nearly worthless; and taking the whole quantity of coal raised per annum in this country at 100 million tons, the waste produced in undergoing by hand labour amounts consequently to as much as 14 million tons per annum.

The compressed air for working the machine is supplied by an air-compressing pump of 18 inches diameter and 2 ft. 10 ins. stroke, worked by an engine that is employed for winding coals up an incline at the bottom of the pit. The compressed air is delivered by the pump into a large air-vessel, 3 feet diameter and 30 feet long, from which it is conveyed along the mine by a wrought-iron pipe 2½ inches diameter and ¼ inch thick, put together with ordinary screwed sockets, and terminating in a portion of 1¼ inch pipe and a long length of flexible tubing of the same size, which is coiled on the floor and drawn out by the machine as it advances along the face of the coal. Great difficulty was originally experienced in maintaining the pressure of the air at the machine when working at considerable distances from the compressing pump; but this has been completely obviated by the introduction of a second smaller air-vessel at the working face where the machine is in operation. This smaller air-vessel is 2 feet diameter and 6 feet long, and is mounted on wheels for the convenience of being quickly removed to any part of the mine. The air-compressing pump is capable of supplying air enough for working three of the coal-cutting machines, but at present there is only one machine working in the pit. There is not therefore the means of ascertaining the actual cost of the steam power required to work the machine; but there is no doubt a great saving over hand labour by the use of the machine.

By the adoption of compressed air as the medium for transmitting the power to work these coal-cutting machines, the important collateral advantage is obtained of improved ventilation at the working faces. The discharge of the exhaust air from the machines delivers a supply of fresh air, free from noxious gas, during the whole time that the machine is working; and the coldness of the discharged air, consequent upon its expansion at the moment of liberation, has a highly beneficial effect in reducing the temperature at the working faces. During the trial made by the writer at the Tingley Colliery, a shot was fired at a short distance from the machine, for breaking down a mass of coal; and although the smoke at first completely obscured the working face and the machine, the whole of it was cleared away in so short a time as two minutes, having been carried off by the current of exhaust air discharged from the machine. In the case of any danger arising from accumulation of gas in the goaf or elsewhere, the means of safety is at hand, as it is only necessary to detach the india-rubber supply pipe from the machine, and discharge a continuous jet of fresh air in the required direction, whereby the gas is speedily dispersed, and the dangerous place rendered safe. Also as the undercutting of the coal is done so much quicker by the machines than by hand labour, the employment of the machines requires a smaller extent of working faces to be kept open for getting the same quantity of coal in the same time; the air has therefore a shorter distance to travel and becomes less loaded with gas, and is consequently safer and more wholesome for the colliers.

In reference to the greater quantity of coal that is got by the use of the machine from a given length of working face in a given time, the quantity got by one man in a day, including undercutting, breaking down, and filling the coal, is 3 tons when undercutting by hand labour, assuming a yield of one ton of coal per cubic yard; and taking a working face of 48 yards length, the four men working on that length of face would therefore get 96 tons in 8 days. The machine however will undercut 96 yards in one day, and this quantity would then be broken down and filled in by four men in two days, making only 3 days for getting the 96 tons with the machine, in comparison with the 8 days required for hand labour. Hence with the machine as much coal can be got from 18 yards length of face as from 48 yards by hand in the same time.

In regard to the danger to which the collier is exposed in holing by hand labour, from the risk of the coal falling down and crushing him while lying with his body inserted partly within the groove which he is excavating, it is evident that this danger is entirely removed by the employment of a machine for performing the holing, as the men are altogether clear of the working face, and the tool alone enters the groove in process of excavation.

Mr. **Fernie** observed that, as some of the earliest attempts at coal-cutting by machinery had been made in the neighbourhood of Leeds, he thought a paper on the subject would be appropriate for the present meeting, especially as the opportunity would be afforded to the members of seeing at work in the same colliery the two different machines described and exhibited to the meeting. Both machines he believed were now proved by the results of actual working to be completely practicable; and he had been much gratified at finding that coal-cutting by machinery was no longer merely an experiment, but that at the Tingley Colliery the whole of the undercutting of the coal, excepting only in driving headings, was at the present time being done by the pick machine, as described in the paper. The removal and relaying of the rails at the working face, as the getting of the coal advanced, was managed in a very simple way at that colliery, by merely turning up sideways against the face of the coal the pair of rails with their sleepers, so as to allow of fixing the new row of props close to the face of the work immediately after the machine had passed along and finished the cut; and the rails were then ready for turning down again into the further position required for the next cut, as fast as the coal already cut was got out and loaded into the corves; by this plan the rails were relaid with the least possible trouble, ready for the next traverse of the machine along the new face of the work.

Mr. W. **Fairbairn** observed that the groove cut by the machines shown in the drawings was represented at a considerable height above the floor of the mine, and he enquired whether it was necessary for the holing to be done so high up in the seam.

Mr. **Fernie** replied that in the position shown in the drawings the machines were holing in a parting of dirt situated at that height above the floor, so that the holing was not done in the coal itself but in the parting; but both machines were arranged for holing also at a lower level, according to the height at which the cut had to be made. In the slotting machine the cylinder carrying the cutter was made to slide vertically on four guide bars; and in the pick machine the height of cut was adjusted by simply sliding the pick itself upon the vertical shaft on which it was keyed, and by this means it could be set to hole in the very bottom of the seam, at the level of the rails.

Mr. W. **Naylor** observed that as the machine was holing in a parting of dirt it had the advantage in that case of undercutting the coal without waste of the coal itself; but in holing half way up the height of the seam, as was there the case, only the upper half of the coal above the cut would be brought down by the creep of the roof, while all below the cut would have to be got out by wedging. He enquired therefore whether it would not be better to hole at the bottom of the seam so as to bring the entire thickness of the coal down at once, instead of in two stages; as he thought such a mode of working would be particularly desirable where the seams of coal were not very thick, like those mentioned in the paper of only 5 feet and 3½ feet thickness. In the slotting coal-cutting machine described in the paper the use of compressed air for working the machine gave a percussive action to the stroke of the tool; but in another machine upon the slotting principle that had been used for coal cutting, the power employed was water pressure, so that the tool was worked with a more gradual and steady movement, like a planing or slotting machine for iron; and he thought it would be of much interest if some information could be given as to the relative value of the two machines worked in these different ways. Any machine which was successful in accomplishing the work of undercutting the coal ought he considered to receive the greatest encouragement from all connected with collieries, as he believed there would be far less liability of strikes among the men where the holing was done by a machine; for although no doubt colliers were difficult to deal with, this was probably due in a great measure to the severe nature of the bodily labour involved in holing, which inclined the men to abandon their work upon the most trivial pretexts; whereas if a machine were employed for the holing, they were spared the heaviest part of the work, and had nothing to do beyond getting out the coal undercut for them by the machine. Moreover to the colliery owners themselves a holing machine would be invaluable in the event of a strike, by enabling them in the emergency to continue the working of the colliery without being dependent upon the regular colliers.

Mr. **Fernie** said that at the colliery referred to in the paper advantage had been taken of the dirt parting in the middle of the seam to do the holing at that height so as to avoid wasting the coal; the top portion was then got out first, being brought down by the creep of the roof, aided by a few shots where necessary; and the bottom part was afterwards broken away by wedging, which was easily accomplished when the top coal had been previously removed. In ordinary cases, where there was no special object in holing above the level of the bottom of the coal, the undercutting would of course be done by the machines at the bottom, according to the usual practice in undercutting. One great inducement to the adoption of a machine for holing had been the difficulty frequently experienced in getting men to do the holing at the bottom of a seam, on account of the great danger they were then exposed to from the creep of the roof bringing the large mass of coal down upon them unawares.

Mr. W. **Firth** explained that another important reason for holing in the parting at the Tingley Colliery, instead of at the bottom of the seam of coal, was that the parting in the seam was a line of division between two different qualities of coal, as was generally found to be the case, the coal above the parting being in this instance of a better quality than that below. If the holing were done at the bottom, so as to bring down the entire thickness of the seam at once, the good quality of coal would get mixed with the bad; and it was therefore better to keep the two sorts separate, by cutting the groove in the parting between them, and breaking down the upper and better portion before getting the bottom coal.

Mr. W. **Fairbairn** observed that not only would the use of a machine for holing prove a great boon to the working collier, by sparing him a great deal of painful toil in undercutting the coal, but it appeared that it was also of great commercial importance to the owners of collieries, by enabling them to get a larger quantity of coal out of the mine in the same time, and with less waste of the coal in holing. In working the machines by compressed air there was the further advantage that the ventilation was improved at the working face by the discharge of the cylinder full of fresh air at each stroke of the machine. Another consideration which struck him as important was that he had observed in the north of England pits that it was sometimes necessary, after undercutting the coal at the bottom by hand, to cut also some vertical slits, in order to bring the coal down in mass; but the facility afforded by the machine for holing in a higher part of the seam, leaving a smaller thickness of coal above the cut, would enable the upper coal to be brought down in mass without more trouble than applying a shot at the top. There would be no difficulty afterwards in getting out the bottom coal below the groove. The adoption of coal-cutting machines was therefore well worthy of consideration, and he hoped before long to see them extensively substituted for hand labour, more particularly as he understood machines were gradually being introduced at several collieries in different parts of the country.

Mr. W. **Menelaus** said he had long been looking for a good practical coal-cutting machine, but the subject was surrounded with many difficulties, on which he thought hardly sufficient consideration had been bestowed. In the first place, if the machine were to do a large proportion of the whole work of the colliery, its introduction would be a comparatively simple matter, because it would unquestionably be of great and immediate commercial advantage. But so far was the holing of the coal, which was the only operation performed by the machine, from forming a large proportion of the entire work of a mine in South Wales, that he considered the holing did not amount there to more than one tenth of the entire work. Although therefore the undercutting was no doubt the hardest and most disagreeable labour in a colliery, it would evidently be difficult to introduce with economy a machine which would only deal with so small a proportion of the work; and he thought this would prove the chief practical difficulty in the way of introducing coal-cutting machines.

With regard to the effect produced upon the ventilation by the air discharged from the machine, he thought the quantity so discharged must be very small compared with the total quantity required for the ordinary ventilation of a colliery. For it appeared the steam engine supplying the air for working the machine had a cylinder of only 20 inches diameter and 3 feet stroke, and he considered it could not therefore send a sufficient quantity of air down the pit to produce any material effect upon the ventilation.

One great advantage might perhaps be anticipated from the use of the coal-cutting machine, namely that by this means the same quantity of coal could be got out of the pit without keeping open so great a length of working face; and it would be an important improvement to be able with the machine to keep open a much smaller extent of working face for the same yield of coal, because if double the quantity could be got from the same faces the interest on capital for the plant in the mine would be reduced one half. With this object there was at present a movement in South Wales for introducing the double-shift system practised in the north of England. so as to keep the pits at work the whole twenty-four hours, instead of letting them stand idle for sixteen hours, as was now the case; the double-shift if introduced was expected to produce a great saving in the cost of getting the coal, but thus far there had been a difficulty in introducing the plan.

The danger to the miners he thought would not be diminished by the use of the machine, as he believed the accidents occurring in working the coal did not generally arise from the coal breaking down upon the collier while holing underneath it, but generally from a fall of the roof outside the face of the coal. There was therefore as great risk of such an accident when a machine was used as in holing by hand labour.

The main consideration at present however, in reference to substituting a machine for hand labour in getting coal, was the small proportion of the whole work that was affected by the machine. If like a lathe or a planing machine it would do all or nearly all of the work, there could be no question it would be highly valuable; but he did not think the value was sufficient to justify its adoption so long as the economy attending it would affect only about one tenth of the work of the mine. Colliery owners had perhaps been thought too backward in the adoption of machinery for coal cutting, but it was necessary that the question should be considered commercially as well as mechanically; and having paid much attention to the subject for many years, he was sorry he could not see that the use of a machine would be economical in the collieries with which he was connected; and he feared it would yet be a long time before machinery superseded hand labour generally for getting coal.

The **Chairman** observed that the waste of coal in holing by the machine was much less than by hand labour, amounting to only about 4 per cent. with the machine in comparison with 12 per cent. by hand labour, as stated in the paper; and he thought the saving of 8 per cent. was considerable enough to be reckoned as an important advantage in coal cutting by machinery.

Mr. W. **Menelaus** said that in the South Wales district the small coal made by the pick in holing was not wasted, but only reduced in value as compared with the large coal; it would however be a great advantage to reduce the quantity of small coal made, and no doubt the machine would effect a saving in that respect.

Mr. W. **Fairbairn** enquired what was the actual difference of temperature at the working faces in consequence of the discharge of the compressed air from the coal-cutting machine. No doubt the quantity of air discharged from the machine was very small in comparison with the total volume of air passing through the mine; but being delivered fresh and cold close to the working face, he thought it must prove beneficial to the men at work.

Mr. **Fernie** remarked that the whole of the heat developed by the act of compressing the air at the surface of the ground became dissipated in the compressing cylinder and in the air receiver at the surface, the compressing pump being surrounded with a current of cold water for the purpose of carrying off the heat; and therefore the full effect was obtained of the expansion, in cooling the air discharged from the machine at the working face below the temperature of the external atmosphere outside the mine, producing consequently an important effect in cooling the temperature at the place where the men were working.

Mr. W. **Menelaus** said he had used compressed air at the Dowlais collieries for working underground engines situated a mile or more from the compressing engine at the surface of the ground; but although the air discharged from the engines was so cold that the exhaust ports frequently became stopped up with ice, the quantity of the air bore so small a proportion to the general current of ventilation that it produced no appreciable effect on the temperature in the mine. The air compressing engine was of much greater power than the one mentioned in the paper, the cylinder being 36 inches diameter with 6 feet stroke.

Mr. W. **Firth** stated that he had found by actual trial that when the machine was working at the usual rate of about 80 blows of the pick per minute, with the air at a pressure of 45 lbs. per square inch, the reduction in temperature in the neighbourhood of the machine at the working faces was about 4° Fahr., namely from about 56° to 52°. An estimate of the volume of air discharged from the machine in working showed that the quantity was not infinitesimal, but quite sufficient to produce a sensible effect upon the temperature and the ventilation at the working faces; for at the rate of 80 blows of the pick per minute, the pressure of the air being 3 atmospheres and the cylinder being 6½ inches diameter with 10 inches stroke, the quantity of air delivered into the mine was 120 cubic feet per minute at the pressure of the atmosphere. This supply of fresh uncontaminated air close to the working faces was found practically to produce a most beneficial effect upon the ventilation in the neighbourhood of the machine.

Mr. C. E. **Amos** observed that the heat developed at the compressing pump, being all got rid of at once as previously explained, represented a corresponding amount of heat extracted from the mine in the neighbourhood of the machine on the expansion of the discharged air; and although the quantity of cold air discharged was small compared with the total quantity of air passing through the mine, yet it was so much lower in temperature that it must make a perceptible difference at the working faces, especially as the discharge took place close to the men.

Mr. S. **Firth** remarked that the practical effect of the cold air discharged from the machine was shown by the fact that the men working the machine or engaged near it were glad to keep their coats on; while at a neighbouring bank in the same pit, away from the machine, they would be found working with their shirts off. The cold was so great at the machine itself that there had been much trouble at first with ice in the cylinder, and it had been necessary to add a stop cock at the bottom of the air receiver at the surface of the ground, in order to run out the water accumulated from the compressed air; this was done every morning before beginning to work with the machine.

They had had a great many difficulties to contend with for many years in endeavouring to apply machinery to coal cutting, but they had now succeeded in doing the entire holing at the Tingley Colliery with one machine, which was a proof that the practical difficulties in the application of the machine had been overcome. Any argument against the usefulness of the machine on the ground that it did not do the whole work of the colliery, but performed only a small portion of the work, seemed to him not to be valid; and if that objection had been allowed to prevail in other cases, mechanical improvements generally would not have progressed as they had done. He was quite satisfied to take success by instalments, without being disheartened at not being successful in all points at once; and the coal-cutting machine described in the paper had been designed solely for the purpose of performing the undercutting of the coal, which was now successfully accomplished by that means. He enquired what was the system of working the collieries in South Wales, and how it was that the holing formed so small a proportion as one tenth of the work, and what was the thickness of the seams of coal worked there.

Mr. W. Menelaus replied that the South Wales pits were worked mostly on the long-wall system with a single shift, leaving the pit standing idle often for sixteen hours; the thickness of the coal seams was from 9 feet down to 2½ feet. The South Wales steam coal was of a very friable character, so that it was worked much more easily and rapidly by the pick in holing than a hard coal would be; and by leaving the pit standing idle for from twelve to sixteen hours, the coal was brought down by the pressure of the roof, without much labour to the colliers in holing. On account of these favourable circumstances the proportion of labour required for holing the coal was so greatly reduced that it did not amount to more than one tenth of the work of the mine. Although he had for many years advocated the application of machinery to coal cutting, he did not yet see how this could be economically accomplished in the South Wales district by a machine which only performed so small a proportion of the work as the holing.

Mr. S. **Firth** remarked that it appeared the only objection raised to the introduction of coal-cutting machinery applied merely to the South Wales collieries, and in that case it was only because machinery was not necessary, owing to the unusually small proportion of work in holing required to be done for getting the coal. There were however many other coalfields where the holing formed a much larger proportion of the entire work, amounting to as much as half the whole work of the colliery in some instances; and to these cases the machine was decidedly applicable. In the north of England two of the pick machines had now been at work for three years, and he understood they had given entire satisfaction and had been found very advantageous. One object aimed at in the double-shift system was he presumed to have only half the number of men at work at a time for the same yield of coal, so that in the event of an explosion occurring only half the number of lives would be endangered; and by the use of the machine for doing the holing, this advantage was realised to a considerable extent, as all the men otherwise employed in holing were absent. It had also been shown in the paper that, by employing the machine, as much coal was now got from a bank of 18 yards length as from one of 48 yards length undercut by hand labour; and one consequence of this diminished area of workings required to be kept open when the holing was done by machine was that in laying out a new pit it was not necessary to drive more than half a mile of headings before beginning to get the coal for market at the full rate of working.

Mr. J. **Warburton** said he had had frequent opportunities of seeing the working of both of the coal-cutting machines described in the paper. From what he knew of the South Wales collieries and the very friable nature of the coal in that district, he thought the mere holing of the coal might safely be put down at not more than one tenth of the entire work. But in the midland counties and in South Yorkshire and other parts of the country, the coal was much firmer and much more difficult to get; and in these districts the holing, all of which would be performed by the machine, amounted to fully one fourth of the entire work of the mine, so that the machine would be applicable with great advantage. In many cases indeed in the midland counties the holers formed a majority of the colliers, so that a machine doing all the holing would perform at least one half of the work in the mine. With regard to the machine not being adapted for cutting vertical slits in addition to undergoing the coal, there was of course no necessity at all for vertical cutting in the South Wales coalfield, where all that had to be done was to undergo the coal, and it then fell down of itself in the natural course while the pit was left idle; and in other districts also he thought it would be preferable to avoid the labour and waste of vertical cuts by working the long-wall system and carrying the holing to a greater depth in from the face, so as to be able to break the coal down without requiring vertical cutting. The statement made in the paper respecting the number of accidents occurring from the coal falling upon the men while occupied in holing was he regretted to say unfortunately too true; and as this danger would be greatly lessened by substituting the machine for hand labour, he thought it was quite right that the safety attending the use of the machine should be reckoned among its advantages.

Mr. G. Gilroy remarked that in the Lancashire and Cheshire district the colliery owners had been for some time anxiously endeavouring to meet with a successful machine for coal-cutting, and at the Ince Hall Collieries near Wigan he had been trying a machine for some length of time, but hitherto without success. Throughout that district as well as in Yorkshire and North Wales he thought it was very desirable that the use of machines for getting coal should if possible be established; and he was satisfied that a successful machine for holing alone, without making vertical cuts, would do at least one half the work of the colliers. The small proportion of the holing in the South Wales coalfield he considered was quite exceptional, and he believed was confined to that district.

With regard to the alleged improvement in the ventilation of a mine by the use of the coal-cutting machines worked by compressed air, he thought too much credit was claimed for the machines in this respect. For although no doubt a considerable cooling effect was produced in the immediate neighbourhood of the machine, he had not found in the trials which he had made that any material improvement took place in the general ventilation of the mine, or any appreciable lowering of the general temperature. The danger also of accidents from the falling of the coal would not be prevented he thought in any great degree by the employment of machines for holing.

Mr. W. **Firth** said he had not been aware previously that nature ever did so much for the collier as appeared to be the case in South Wales, where it seemed the men had little to do beyond going into the pit and fetching out the coal already got for them by nature with only a small amount of labour for holing. Under such circumstances, however desirous the proprietors of a colliery might be to substitute machinery for hand labour, there was manifestly no scope for the employment of a machine with any material economy of working. In other coalfields however, such as those of Yorkshire, Lancashire, and Cheshire, great difficulties were experienced in getting the coal, the seams being often very thin and lying at a considerable inclination, the coal of hard quality, and the roof and floor bad; and in these districts therefore he thought there could be no question as to the great advantage of introducing coal-cutting machines.

Mr. **Fernie** observed that in introducing machinery for coal cutting it was quite possible the work might at first have to be done at a slight loss by the machine until the new mode of working was fully established, after which there could however be no doubt as to the gain that would ultimately result. Where a pit had been originally laid out on the long-wall system in a manner suitable to the application of a machine, there was no difficulty at all in substituting machinery for hand labour; and this was the case at the Tingley Colliery, where already the entire holing was done by the machine. At present indeed the pit was perhaps not being worked actually cheaper than by hand labour, owing to the circumstance that at the present rate of getting the coal there was not a sufficient amount of work in holing to keep the machine fully occupied; but when a sufficient number of banks were opened to keep the machine always at work, there was no doubt that the large yield of coal then obtained by the aid of the machine would be got with only half the number of men that were required when the holing was done in the ordinary way by hand labour. Though at present it had not been possible to succeed in getting the entire work of the colliery done by machinery, that was no reason why the substitution of machinery should not be accepted for performing an important part of the work. The pick machine in use at Tingley Colliery was of very simple construction throughout, and was worked by an ordinary collier, who managed it entirely; no skilled mechanic was required to work it or keep it in order, as there was no complication in any of its parts.

Another point to be considered in connection with the use of machines was, what was to be done when much deeper mines had to be worked than at present. When the present coal seams were exhausted it would be necessary to go deeper, and the deeper pits would require better ventilation; and he thought hardly sufficient importance was attached to the advantage attending the use of machines worked by compressed air, in respect to their effect upon the ventilation at the working faces. The air that came out of the machine was not like the ordinary air which arrived at the working faces after traversing a long length of passages through other parts of the mine; but it was brought pure and fresh from above ground, free from all contamination, and was discharged from the machine cool and grateful to the men, and at the very spot where it was most needed and most acceptable. This appeared to him a practical advantage which would prove of great value, particularly in the working of deep pits.

Mr. W. Menelaus wished it to be understood that the difficulties which occurred to him in connection with the employment of machinery for coal cutting did not arise from any objections to the particular construction of either of the machines described in the paper, and he did not think that either of them could be considered at all complicated. With reference to their mode of action, he had not had an opportunity yet of witnessing the working of the two machines, but the slotting principle appeared to him more consonant with other mechanical operations than a simple imitation of the action of the pick in hand labour.

Mr. W. **Moor** said that at the Hetton Colliery they had had two pick machines at work for six years, and had found them answer exceedingly well. They were driven by compressed air, and the effect of the cold produced by the discharge of the air from the machine was just what had been described, that ice was formed in the slide-valve chest; but this was obviated by preventing the accumulation of water there.

Mr. E. **Williams** thought it somewhat remarkable that the machine which had been in use for six years at Hetton had not yet made its way into any other of the numerous collieries in the neighbourhood. The object of the proprietors of collieries was to get the coal cheaper; and the existence of this machine at one pit for so long a time, without spreading to other collieries, led him to infer that there could not be any great saving in its use as compared with hand labour. He thought that the holing of the coal did not constitute a sufficiently large proportion of the work of a colliery for the substitution of machinery to be productive of any very material saving.

Mr. W. E. **Marshall** observed that the cost of undercutting the coal and the proportion which that operation bore to the whole work of the mine would vary according to the thickness of the seam of coal worked; and it was therefore to be expected that there should be considerable differences in the cost of getting in different districts, as the holing of a thick seam was done at a much smaller cost per ton of coal got than in the case of a thin seam. In regard to the statement that the entire holing of the coal at the Tingley Colliery was now done by machinery, he enquired what was the extent of the work done in holing at that colliery, as he thought that to do all the holing in a colliery of ordinary size would require several machines to be used. He asked further whether any risk had been observed from the pick striking fire in working, and whether the dust produced by the pick did not seriously affect the health of the miners; and also whether the noise made by the exhaust air discharged from the machine was not a serious hindrance in the way of hearing the sounds of the creeping of the roof, which were the warnings to the men as to the safety of the workings. He himself took a great interest in the application of machinery to coal cutting, which he considered to be a subject of vast importance; and he had found many difficulties and prejudices to contend with in working machines underground, where it was not possible to watch every process with the same ease as in the case of machinery working by daylight and in workshops.

Mr. S. FIRTH replied that at the Tingley Colliery they had at present only sixteen banks open, of 50 yards length each; and as the holing of these was done by the machine at the rate of five banks per day in regular work, there was not at present full work for the machine. They were now however driving fifteen additional new banks to be worked by the same machine, and when these were opened, he intended to start a second machine also, as a precaution against any delay by accidental stoppage of the present machine. At this colliery no coal was now cut by hand labour, but the machine did the whole of the undergoing. As to the proportion which the holing constituted out of the entire cost of getting the coal, the cost of holing by hand labour at some of the other collieries in the neighbourhood was about 15*d.* per square yard of holing, and the cost of filling was 4*d.* per ton, and of breaking down about 2*d.* per ton; and as a ton of coal was about a cubic yard, taking the seam of coal worked to be about 3½ feet thick, the cost of holing by hand labour would in these cases be more than three times that of filling, or fully half the entire cost of getting the coal.

In holing by the machine, the pick caused sparks to fly occasionally, but he had never found it necessary to squirt water into the groove for preventing danger from fire; and he had never had any ignition or explosion of gas from that cause, and did not expect ever to have any, because the draught was so great at the machine that any gas issuing from the coal was completely carried off by the air.

Mr. G. **Gilroy** said that, from his own experience with the coal-cutting machine which he had tried, working a pick like that used in hand labour, he did not think the dust arising from the working of the machine caused so much inconvenience to the men as in holing by hand, because they were not obliged to be so close to the work; and with regard to the liability of sparks being produced by the blows of the pick, he did not see that there was any greater risk with a pick worked by a machine than with the ordinary pick worked by hand. The difficulties which he had met with in endeavouring to adopt machinery for coal-cutting had been in applying a machine day by day to the ever varying conditions of a mine, even though the machine itself might be mechanically correct. One requirement which he thought essential to the practical success of a coal-cutting machine was that it should be very portable, so that a man or a man and a boy could readily move it 20 or 30 yards without a tramroad; for one of the difficulties which he had experienced in working a pick machine consisted in keeping the tramroads sufficiently level and the sleepers packed securely enough, so as to resist the blows of the machine and not be pushed away by them from the face of the coal; and the tramroad had to be kept level enough to ensure the pick cutting out a level groove. All this required great attention, and had formed an obstacle to the introduction of machinery; he hoped however that these difficulties would ultimately be got over.

Mr. H. **Lawrence** remarked that the Hetton Colliery was not the only one in the north of England where coal-cutting machines had been successfully adopted; for he had recently been down the Nedderton Colliery near Bedlington, Northumberland, and found that two hydraulic machines on the slotting principle had already been in use there for some time, and a third also was about to be put to work, which showed that the two previous ones must have proved advantageous. One consideration to be borne in mind in relation to getting coal by machinery was that there were very many narrow seams of coal, as yet unworked on account of their thinness, which, as coal became more and more valuable, it would be necessary to work. But if it were attempted to work by hand a seam of only 2 to

2½ feet thickness, the greater part of the coal would be broken up and wasted by the mere holing. If however a machine were employed to undercut in the shale at the bottom of the coal seam, the whole thickness of the seam would be obtained as valuable coal, and could thus be worked with profit. This was already being done at the Nedderton Colliery, where they were now working by the hydraulic machine a very narrow seam, only 2 ft. 6 ins. thick, which it would not pay to work by hand. In this case the heading in which the machine was working was not more than 3 ft. 6 ins. high, and the tubs for conveying the coal away were made to rest on the axles, leaving only just room enough for filling between the top of the tub and the roof. At that colliery the machines were kept at work all night with two or three men to attend them, and they undercut in the night as much coal as the colliers could break down and fill during the whole of the next day.

Mr. W. E. Marshall thought the machine working on the slotting principle had obviously an advantage in one respect over the pick machine, that it cut the groove to the full depth at one operation, whereas it appeared the pick machine had to go over the work a second time in order to complete the cut to the required depth. This involved the trouble and delay of bringing the machine back to the starting point, and he thought there might be some difficulty in getting the pick to strike correctly in the same groove in the second course. He enquired whether there was ever any trouble from the pick machine being thrown off the rails by the violence of the blows given with the pick.

Mr. Fernie replied that it occasionally happened that the pick machine got thrown off the rails in working, and this had occurred during the trial that he had made of the machine. It was however got on the rails and at work again in one minute, the collier having a belt round his waist from which a short chain was hooked to the machine, so that by straightening his back he easily lifted the machine on the rails again without any material loss of time. The slotting machine was of course very steady in working, being held down securely upon the rails by the upward pressure against the roof. The noise made by the discharge of the exhaust air from the machines had not, he believed, been found any inconvenience; no doubt there was more dust than in using the ordinary pick, as the amount of work done was so much greater.

Mr. S. Firth said it had been the practice hitherto with the pick machine to do the holing in two courses, as described in the paper, first with the shorter pick, and afterwards with a long pick finishing the cut to the required depth, the object having been to avoid getting the pick continually choked in the groove by attempting to cut to the full depth in a single course. He had now however adopted a sort of double-headed pick, long enough to hole to the full depth of cut when it was required to cut a yard deep at one course over, and having the second head fixed to the arm of the pick at a shorter radius and shaped with a broader face than the cutting head; so that in the back stroke of the tool this second head swept the rubbish out of the groove and kept it clear. With this pick the holing was now done in a single course, and the rate of holing with it was 30 lineal yards per hour, undercutting to a depth of more than 3 feet in from the face.

Mr. T. Hawksley remarked that the question of the relative merits of hydraulic and pneumatic machines was a subject which he had had occasion to study under a great many aspects; and there were two considerations which led him to think that, as applied to getting coal, a pneumatic machine must ultimately be found superior to one worked by hydraulic power. In the first place, air when in motion was subject to very much less friction than water; and even when the air was compressed to three or four atmospheres he had found that the friction amounted to only 1-12th or 1-14th of that of water, in travelling through a tube of the same dimensions. The other consideration was that with a hydraulic machine there was the water to be got rid of; because as long as the machine was worked by a supply of water from the top of the pit, the water so sent down had all to be pumped up again, like the rest of the water in the mine, and there would consequently be a considerable loss of power. That loss would of course not be quite so serious if it could be managed to supply the water pressure to the machine by means of a steam engine worked at the bottom of the pit, because the water would then be repeatedly used without being pumped up to the surface and sent down again, which was an operation attended with loss by friction and other inconveniences. These two points he thought were in favour of a pneumatic machine, as compared with one worked by hydraulic power. Moreover a machine worked by compressed air, according to the extent of its application, did certainly contribute to the ventilation of the pit, and to the cooling of the air in the immediate vicinity of the place where it was working. In the case of the Kremnitz machine for making artificial ice by the expansion of air previously compressed, which had now been in use for more than eight years, the water issuing with the jet of air was frozen instantaneously by the expansion of the discharged air, and issued from the machine in the form of pellets of ice, which were ejected with considerable force. Therefore, although there were some advantages of another kind in favour of water power, he was inclined to pneumatic machines as better and more convenient for such a purpose as coal cutting. He was also inclined to prefer a machine acting upon the slotting principle for undercutting the coal, which he thought was a more mechanical contrivance and appeared likely to work more advantageously than an attempt to imitate, perhaps somewhat imperfectly, the action of the ordinary pick wielded by the collier; and it would probably reduce a smaller proportion of the coal to powder, by reason of making rather narrower a slit. This was a point however which could only be decided by the actual circumstances of the working of the two descriptions of machine.

The CHAIRMAN moved a vote of thanks to Mr. Fernie for his paper which was passed, and also to Mr. Firth and Mr. Donisthorpe for the excellent arrangements which they had so kindly made for affording the members an opportunity of witnessing the working of the coal-cutting machines.

The Meeting was then adjourned to the following day. In the afternoon the Members visited various Iron works and Engineering works in Leeds and the neighbourhood, which were opened to their inspection during the days of the meeting.

The Adjourned Meeting of the Members was held at the Philosophical Hall, Leeds, on Wednesday, 29th July, 1868; **WILLIAM FAIRBAIRN**, Esq., Past-President, in the Chair.

The **CHAIRMAN** alluded to the recent munificent gift to the country by Mr. Whitworth of the sum of £100,000, for the establishment of thirty annual scholarships of £100 each, to be held by workmen going through a thorough course of scientific and artistic training; and he had great pleasure in moving the following resolution in recognition of Mr. Whitworth's munificence:—"That "this Meeting expresses the high sense it entertains of the eminent "service rendered to the country by the munificent gift of Mr. "Whitworth for the creation of scholarships in practical science "and mechanical art."

Mr. T. **HAWKSLEY**, in seconding the resolution, said he was sure they all felt deeply indebted to Mr. Whitworth for this practical endeavour to promote a class of instruction which would prove of great advantage to the country; and in acknowledging his munificence, they desired to recognise not only the magnitude of the gift itself, but also the appreciation which it showed of the real wants of the present age, and of the demand that had arisen for a more thorough practical study of science and art.

The resolution being put to the Meeting was carried unanimously.

The following paper was then read:—

DESCRIPTION OF A TRAVELLING CRANE WORKED BY CLIP DRUM AND WIRE ROPE.

By Mr. JOHN FERNIE, of Leeds.

Few mechanical improvements have been so rapidly and so extensively adopted as the quick-rope Travelling Crane, introduced by Mr. Ramsbottom at the Crewe Works, a description of which was given by him to this Institution in 1864. During the short interval that has since elapsed, the extension of the application of this system has been so great, that at the present time there is scarcely a shop for the manufacture or repair of locomotive engines but has several of these cranes at work.

The Travelling Crane forming the subject of the present paper has been invented at the Steam Plough Works, Leeds, where there has been great experience in the manufacture and working of steel wire ropes; and the idea occurred that an improvement could be made by adopting a steel wire rope working with a clip drum, instead of a cotton rope acting by friction only; and that for out-door work, in quarries or over docks for shipbuilding, where a cotton rope would be subject to injury by exposure to the weather, a steel wire rope would be preferable. A case has indeed recently arisen where it would be impossible to make use of a cotton cord, the crane being employed in a large armour-plate mill for carrying away the plates on leaving the rolls; and the heat from such large masses of iron is so great that a cotton cord as usually applied would be quickly burnt up. For the same reason it has been found necessary in this instance that the man working the crane should be kept at a distance from the heat, and he is therefore stationed in a box at one end of the travelling frame, instead of being placed immediately over the work as usual.

The application of a steel wire rope and clip drum for communicating power formed the subject of a previous paper read before this Institution by the late Mr. John Fowler and Mr. David Greig on the application of steam power to the cultivation of the soil (see Proceedings Inst. M.E. 1865 page 55); and the crane now to be described is only a further adaptation of the same means for communicating power at varying distances from the prime mover.

This Crane is employed at the Steam Plough Works, Leeds, for lifting locomotive engines and other heavy work ranging from 15 tons downwards; it has a span of 40 feet, and traverses a length of 180 feet. The three different motions, for longitudinal traverse, cross traverse, and hoisting, are all derived from one endless steel wire rope, ¾ inch diameter, and weighing 2 lbs. per yard. This rope is driven at a speed of 4 miles an hour by means of a clip pulley fixed at one end of the shop, which is driven by belts and gearing from the engine working the shop. The rope extends the whole length of one side of the shop, going and returning on the same side at the level of the traveller, and passing round a loose pulley at the further end of the shop. The rope is entirely unsupported between the two ends of the shop, and is not strained tight, but hangs loose with only a slight tension, because the peculiar action of the clip pulley allows of the whole power being communicated to the rope by the grip of the pulley through half its circumference, even when the tail rope is entirely slack.

The construction of the crane is shown in Figs. 1 to 11, Plates 82 to 87. The clip pulley A, Fig. 1, fixed at the end of the shop, is speeded to drive the wire rope B B at the rate of 4 miles per hour, and lays hold of the rope with an amount of grip proportionate to the strain thrown upon the rope by the load, releasing it from its grasp when the rope has passed the centre line. The construction and fixing of the moveable jaws or clips round the circumference of the clip pulley is shown one third full size in Figs. 10 and 11, Plate 87. At one end of the travelling platform C of the crane is fixed another clip pulley D, Figs. 3 and 4, of the same size and construction, round which the same wire rope passes, making three quarters of a turn round it. The rope then passes on to the further end of the shop, and round the grooved pulley E at that end, Figs. 1 and 3; this pulley is centred in a sliding frame provided with an adjusting screw G, for tightening up the rope to any tension required. It has not been found necessary to have any sliding weight attached to this frame, for variable tension of the rope; nor indeed has the original adjustment been altered since the crane was first put to work about two years ago. The wire rope has no slippers or carrying pulleys to support it, and is consequently free from the friction that accompanies their use; nor is it proposed to put any carrying pulleys for distances under 600 feet. The shop in which the present crane works is 180 feet long, and the rope hangs in a catenary curve through that distance, the deflection from a straight line being from 3 inches to 2 feet, according to the degree of tightening by the end pulley E.

The gearing for working the longitudinal traverse and the cross traverse is of the ordinary description, the motion being communicated from the clip pulley D on the traveller by means of friction clutches. The longitudinal traverse has a speed of 30 feet per minute, and the cross traverse 20 feet per minute.

The lifting gear consists of a very long cast-iron nut or screwed barrel H H, extending nearly the whole length of the traveller, as shown in the plan, Fig. 2, and to a larger scale in Figs. 5 and 6, Plate 85; and inside the barrel works a short screw I, Fig. 5, sliding on two feathers upon the long shaft J J, which is driven by a friction clutch from the clip pulley D on the traveller, so that by the revolution of the shaft the screw is traversed along within the barrel. The long driving shaft J is supported at intermediate points of its length by the two sliding brass steps K K, Figs. 5 and 7, sliding along freely within the barrel H, and kept apart from each other at the distance of half the length of the barrel by the long rod L; by this means the shaft J is never left unsupported for more than half of its length. The screwed barrel H is cast in two halves longitudinally, and bolted together, as shown in Fig. 6; and the pitch of the screw thread is 1¾ inch, the diameter being 6½ inches.

One end of the hoisting chain being attached to the screw frame M, Fig. 5, the chain N passes along through the inside of the barrel H, round a pulley P, Fig. 2, at the further end of the traveller; then over a pulley on the cross-traversing carriage R, Figs. 8 and 9, down to the snatch-block S, and up again over a second pulley on the carriage R; and the end is attached to the nearer extremity of the traveller at T, Fig. 2. There is no reason however why an ordinary crab might not be used, worked by a shaft extending from end to end of the traveller; and that plan is adopted in a second crane now being erected at the Steam Plough Works, and also in the crane for the armour-plate mill previously referred to; but for heavy weights it is still considered that the long screwed barrel above described is preferable. The crane has two speeds for the lifting gear, one being at the rate of 6 feet per minute, and the other at the rate of 3 feet per minute; and at the latter speed the crane is calculated to lift 15 tons.

It is most desirable that all machinery of this kind should be kept constantly running, so as to be available for immediate use at any moment when required, without any delay for starting it to work; but inasmuch as the total time during which the crane is actually in use does not amount to more than about one hour out of ten, it is of special importance that the power employed to drive the rope when the crane is not in use should be reduced to as small an amount as possible. If a quick-running rope is employed, the absorption of power for keeping it in constant motion forms a large proportion of the total power required when lifting a load, and this is a loss which is always going on throughout the day; but when a slow speed of rope is employed, this constant loss is greatly reduced. The pull required to put the wire rope in motion when the crane is standing idle is 128 lbs. When lifting a load of 10 tons at the usual speed of 3 feet per minute, the additional pull upon the rope due to the load is 191 lbs., making the total pull 319 lbs.; and the horse power required with the wire rope is consequently 3·4 horse power with a load of 10 tons, and only 1·4 horse power when standing idle, these amounts being very much less than in the case of the quick-moving cord crane.

This crane has been in use at the Steam Plough Works for two years, and has been found to be easily and cheaply worked; and not the least of its recommendations is that it is almost noiseless. The original wire rope is still working, and appears at the present time practically as good as the day it was started.

Mr. W. Clay observed that in the use of cranes driven by a quick-running cotton cord he had found it impossible during the recent cotton famine to get cotton cords that would stand for any considerable length of time, as the only cord that could then be obtained for the purpose was made of common Surat cotton, which was not good enough to stand the work. Under these circumstances he had got over the difficulty by using a hide rope, which was found to last for about eighteen months without any serious wear and tear. Although therefore the wire rope now described might be a great improvement over the ordinary cotton cord, still as there were already so many cranes at work driven by the quick-running cotton cord, it might be useful to know that a hide rope could be employed for the same cranes, and would last longer than the cotton cord.

Mr. E. A. Cowper enquired whether any trial had been made of running a light steel wire rope at the same speed as the cotton cord, and so using it to work one of the cranes hitherto driven by the cotton cord. In the crane now described he thought the lifting speeds of 3 and 6 feet per minute seemed rather slow in comparison with the longitudinal and cross traversing motions of 30 and 20 feet per minute; and the latter were perhaps rather faster than usual in such cases.

Mr. Fernie believed that in engineering shops generally the speed of 6 feet per minute for hoisting light loads would be considered amply sufficient; and for heavy work 2 feet or even

1½ feet per minute was enough, and in the 25 ton traversing crane at the Crewe Works the lowest speed of lifting was not more than 1½ feet per minute. With regard to the use of a light steel wire rope in place of the present cotton cord, he did not think it would be possible to run even the lightest wire rope at anything like the speed of 40 or 60 miles an hour at which the cotton cord was driven, because the much greater weight of the steel rope would tell so seriously at a high speed, and the frequent bends would greatly reduce its durability; the important advantage in the cotton cord, which allowed of its being run at such a high speed, was its lightness.

Mr. D. Greig said they had now had considerable experience at the Steam Plough Works in driving cranes with both cotton and wire ropes. They had used one of the light rope cranes for four years, and had found it of great advantage as compared with previous modes of working cranes; but the cost of working and the power required to keep the cord constantly running at the high speed were so great, as well as the wear and tear, that they had been led to look for some other mode of driving, as that plan of crane was found so useful that they wished to retain it. The experience gained in the successful use of steel wire ropes for steam ploughing machinery suggested the adaptation of the same mode of driving for the crane; and the result had been that the crane described in the paper had now been in regular work for two years, during which time it had not cost 25*s*. for keeping it in repair. With the light cotton ropes running at a very high speed he understood it was the general experience that they were found difficult to keep in repair; and the slow moving rope was not only less expensive in this respect, but also had the advantage of giving the same power for lifting without costing nearly so much for the power for driving the rope continuously at a very high speed during all the time that the crane was standing idle. As the crane was required to be always ready for work at a moment's notice, without the delay of having to send men aloft to work the crabs of a hand crane, it was necessary for the rope to be kept constantly running; nor was it practicable to economise the power in the case of the quick-running rope, by stopping it at the times when the crane was not in use, because in starting it again the length of time required for getting up the high speed was as much as five minutes. Considerable difficulties had been met with at first in adapting the wire rope and clip drum to work the cranes; but these had now been successfully overcome, and in the course of a few months there would be several more of the wire-rope cranes at work in other engineering shops. At his own works the use of the wire-rope crane in the erecting shop had been attended with a very great saving in the expense of lifting all descriptions of work in the shop. To work the cranes by a light steel rope driven at the same speed as the cotton cord would be quite impracticable, on account of the weight of the steel rope and the number of bends it would have to make round pulleys of small diameter. The speed at which the wire rope was driven had nothing to do with the speed of lifting, the latter being previously determined by the proportions of the gearing, so as to give two speeds for lifting, 3 feet and 6 feet per minute, with a constant speed of 4 miles an hour for the rope; and the only effect of changing from the lower to the higher speed in lifting was to double the strain on the rope, without requiring the speed of the rope to be altered.

Mr. E. A. Cowper enquired what was the actual strain upon the wire rope at the two speeds of lifting.

Mr. D. Greig replied that in lifting loads of 10 tons and 15 tons at the usual speed of 3 feet per minute the strain upon the rope was from 3 to 4 cwts.; and even if the same loads were lifted at the higher speed of 6 feet per minute, the strain on the rope would not exceed 4½ to 6½ cwts. A rope of that size however, ¾ inch diameter, would safely bear a pull of 15 cwts. in steam ploughing machinery. The main object in using the wire rope for working the crane was to run the rope as slow as possible, requiring of course a corresponding increase of strain upon the rope; and the limit to the strain that could be put upon the rope would be the amount of adhesion of the carrying wheels of the traveller upon the rails, so that the crane should not only be able to stand stationary against the pull of the rope, but should also be capable of travelling in the opposite direction to the pull.

Mr. C. W. **Siemens** mentioned that at the Paris Exhibition in the previous year a plan had been shown of transmitting power to a great distance by means of a steel wire rope driven at a very high speed and running over large pulleys; and this plan had been employed in the mountainous districts of France and Switzerland for transmitting the power from a water wheel or turbine to a distance of half a mile or more up a mountain. There was less wear in this case he understood than was usually experienced in the working of wire ropes, probably owing to the circumstance that the distance travelled by the rope without any bends was so great, the bends being perhaps not more than one at each end of the entire distance. The rope was not driven by a clip drum, but by pulleys of 6½ feet diameter; and the intermediate carrying pulleys were also of large diameter. The speed of the rope was very great, but the strain upon it was small because of the speed; and he had been informed it was found to perform the work exceedingly well, transmitting a large amount of power.

Mr. E. A. **Cowper** thought in the case referred to there must be a considerable amount of sag in the rope between the carrying pulleys, as there was not a heavy pull upon it to keep it up.

Mr. H. **Chapman** mentioned that the quick-running wire rope shown at work at the Paris Exhibition on Hirn's plan had broken shortly before the Exhibition closed; it had been at work about seven months, driving a centrifugal pump of about 25 horse power at a distance of 500 feet, the rope being rather less than ⅜ inch diameter.

Mr. **Fernie** observed that in the crane now described, driven by a wire rope running at a slow speed, the main feature was the application of the clip pulley for driving the rope; and the important practical advantage attending the clip drum was that it did away with the sawing action of the rope in the ordinary V groove of a pulley, the clips laying hold of the rope with an amount of grip proportionate to the pull upon the rope, and holding it absolutely fast at the moment, and afterwards completely releasing it from their grasp as soon as it arrived at the point where it was a tangent to the pulley. By this means any power that was desired could be transmitted by the clip pulley, without involving either the loss from friction or the wear and tear of rope attending the use of the ordinary grooved pulleys. Another advantage of the new plan was the low speed at which the wire rope had to be driven, in consequence of which the power required for driving it was only 1½ horse power when the crane was standing idle, and 3½ horse power in lifting a load of 10 tons at 3 feet per minute, the rope running at a speed of only 4 miles an hour. From experiments made with the previous crane at the Steam Plough Works, driven by the cotton cord running at 40 miles an hour, he had found that the power expended in driving the cord while the crane was standing amounted to as much as 12 horse power, and to 14 horse power when lifting a load of 10 tons at 3 feet per minute. This amount of driving power seemed so disproportionately great as to lead to the supposition that the crane must have been of defective construction in some respects; but even supposing that were the case, he was satisfied the quick-running cord absorbed under favourable circumstances at least four times as much driving power as the slow wire rope. As a workshop crane was required to be always ready for use, it was important that it should be kept in readiness with the smallest constant expenditure of power during the time it was standing idle; and this was satisfactorily accomplished in the wire-rope crane, by keeping the rope always going at the slow speed.

Mr. D. Greig said he had kept an account of the time during which the crane was in actual use, and had found it did not average more than one hour in each day, as so much time was consumed in the intervals between lifting, traversing, lowering, and fixing the work moved by the crane; but the rope had to be kept going continuously during the whole time, in order that the power might be ready for instant use whenever required.

Mr. B. Walker said he had one of the quick-running cranes in use at his own works and had also made several of them, and he did not think the power required for driving the cotton cord was so great as had been mentioned; he considered there must have been something defective causing extra friction in the crane which was found to absorb so large an amount of driving power, as the pull upon the cord required for lifting the load alone was only about 1 lb. per ton of load when the cord was run at 60 miles per hour. He had also made one of the wire-rope cranes for Woolwich arsenal, in which the rope was driven at 6 miles an hour under a constant pull of 10 cwts.; and although it was certainly found to take less power for driving than the quick crane, he did not think the difference was so much as one in four, and he doubted whether the quick cord took more than twice as much power as the slow wire rope. As regarded the durability of the cord, there was no doubt that the quick crane was troublesome, notwithstanding that the wear and tear had been considerably reduced by taking care to diminish the friction as far as possible, by employing well-made pulleys and having as few bends as possible in the cord. But at the Crewe Works he understood one of the cotton cords had now been at work for seven months and was still in use; and the quick-running cranes employed there had been found so satisfactory that it had not been considered desirable to change to any other plan. He thought however, if the wire rope was found to be durable, that the slow-going wire-rope crane would become more general, because it did not require such good workmanship as was necessary in the high-speed crane.

Mr. C. E. Amos remarked that he had seen the working of the wire-rope crane at the Steam Plough Works and could fully endorse what had been stated as to its advantages; it appeared practically a very useful machine, and he thought the principle of using the wire rope running at a slow speed was the correct one. He was certainly surprised at the very great amount of power required in the quick crane to drive the cotton cord at 40 miles an hour, and thought there must be some undue friction in that case, as the crane should not take anything like so much power for merely overcoming the friction. As to the durability of the cotton cord, if it did not last much more than seven months, he thought that would be a serious objection to the quick-running crane; and in many engineering shops he considered it might then be even better to return to hand cranes, than to be liable to a breakage of the driving cord occurring perhaps at a time when the crane might happen to be most wanted for a press of work.

Mr. F. J. **Bramwell** observed that, although the power necessary for driving the quick-running cord appeared at first sight excessive, it must be borne in mind that, with the very high speed which was employed, a very small increase in the constant pull upon the cord soon mounted up to a large power; for at a speed of 40 miles an hour the pull upon the cord corresponding to a power of 1 horse power was no more than about 10 lbs. If therefore the pulleys of the crane were at all out of order, the small extra friction thereby occasioned would be sufficient at that high speed to account for a considerable increase in the driving power.

Mr. E. H. **Carbutt** thought the old plan of driving the crane by means of a shaft of square section running the whole length of the shop was preferable to the quick cord, because the power required to keep the shaft in motion while the crane was standing was altogether insignificant. A crane on that plan had been in use at his works for ten years, without any breakage of the driving shaft, and without any expense for repairs beyond ordinary wear and tear.

Mr. E. **Reynolds** suggested that one important source of friction in the quick-running cranes might be the worm and wormwheel employed for working the crab, the rubbing surfaces being made at such an inclination that the load upon the crab would stand in any position without running down, though no friction break was used; and he remembered it had been mentioned in the former description of the cranes at the Crewe Works, in which a wormwheel was employed, that a load on the crab, which would be equal to only 6 lbs. pull at the circumference of the driving pulley, was found to require as much as 17 lbs. to start it in lifting, showing that 11 lbs. or nearly double the theoretical power was absorbed in merely overcoming the friction of the worm when standing. Although arrangements of this class were sometimes very convenient, it should be remembered that any machine in which the friction was sufficient to sustain the load, and to check it if descending, must lose or consume in friction at least one half the power employed in hoisting.

Mr. B. **Walker** said that, with regard to the loss of power occasioned by the friction of the worms in the quick-running cranes, they had made several of the cranes lately without the worms, the chain barrel of the crab being driven by spur gearing instead of the wormwheel; and in those cases the power required for working the crane was found to be considerably less than with the worms.

The **Chairman** considered the important feature in the wire-rope crane now described was undoubtedly the clip pulley, by which the application of the wire rope driven at so slow a speed had been rendered practicable; and it was this beautiful invention which had led to such successful results in the employment of wire ropes for the purposes of steam ploughing and cultivation. In the quick-running crane he thought there must certainly have been something wrong to require so great an amount of power as had been mentioned for working the crane; but he considered there could be no question as to the saving of power that would be effected in the present plan with the use of the clip pulley, by running the driving rope at a slow speed.

He proposed a vote of thanks to Mr. Fernie for his paper, which was passed.

The following paper was then read:—

ON THE CORLISS EXPANSION VALVE-GEAR FOR STATIONARY ENGINES.

By Mr. WILLIAM INGLIS, of Manchester.

At the present period of steam engineering it may be said that in the complete practical application of the expansive action of steam rests the only prospect of further economy, excepting that arising from improvements in the generation of the steam; and this practical application of the expansive action of steam has been, and still continues to be, a subject of great difficulty, from the fact that among the many plans of expansion gear very few answer even approximately the intended purpose. The Corliss Expansion Gear for Stationary Engines, forming the subject of the present paper, has until the last few years been little known in this country. The rapid increase of its application however, which has now taken place in this country, has warranted its being brought under the notice of the Institution.

The Corliss engine introduced by Mr. Corliss in the United States about twenty years ago, which in all except the cylinder with its valves and valve-gear is substantially the same as any ordinary steam engine, embodies in the arrangement of the cylinder and valve-gear several principles that had previously been used separately.

First, independent ports are used for admitting and for exhausting the steam at each end of the cylinder, with four separate slide-valves worked from a single eccentric.

Second, the steam is cut off from the cylinder by the main steam valves, without the employment of any supplementary valves for the purpose.

Third, the steam valves are opened against the resistance of springs, and a liberating gear is employed by which the valves are disconnected and left free to be closed by the springs.

Fourth, after the valves are closed, the springs are brought to rest without shock by the application of the contrivance known as the "dash-pot." This consists of a small cylinder with closed bottom, in which a piston is fitted to work easily; and by a suitable arrangement of openings the air is admitted freely to the cylinder while the piston is moving, except when it approaches the bottom, at which time a certain amount of air is imprisoned, forming a cushion to prevent any shock when the piston actually reaches the bottom.

Fifth, the speed of the engine is regulated by the governor acting on the steam valves to cut off the steam earlier, instead of acting on a throttle-valve to reduce the pressure of the steam.

It is the embodiment of these several principles, and the arrangement and construction of the details in the mechanism employed, rather than the application of any new or untried principle, which constitute the special features of the Corliss valve-gear.

Cylinders with four separate passages and independent steam and exhaust slide-valves were used by Seaward previously, the valves employed being flat slides, but not worked in connection with any liberating gear; and a number of marine engines were made on this plan. In the earlier Corliss engines Seaward's cylinders and slides were used; but the valve now employed is a cylindrical slide working in the arc of a circle on its seat, and receiving a rocking motion from a central valve-spindle. Although separate valves and passages were employed previously for steam and for exhaust at each end of the cylinder, the motion imparted to the steam valves was invariable, and any expansion of the steam was effected by the lap of the valve. The speed of the engine also had to be controlled by throttling or shutting off the steam with a supplementary valve; and in this respect the first step in advance is made in the Corliss gear by the addition of the principle of liberating the steam valves. With the employment of liberating gear it became necessary that an independent force should be available for closing the valves when they were detached, and for this purpose weights were first used; but springs have since been substituted for the weights, because they are quicker in action, effecting a sharper cut-off, and are better adapted for quick working.

Liberating gear for the steam valves was indeed used by Watt, so that the principle may be considered almost as old as the steam engine itself; but in Watt's time it was more frequently for opening than for closing the valves that the weights used in that method of working were employed, and as might be expected the mechanism was not very perfect in its details. At that time the drop or poppet-valve was used for the purpose.

To Mr. Sickles of New York is due the credit of perfecting the liberating gear as applied to the poppet or the double-beat valves, in the cut-off gear which bears his name. In this valve-gear, which was introduced in 1841 in America, the dash-pot is applied direct to the valve itself, to arrest the progress of the valve and prevent it from striking on its seat. It should be observed that there is an essential and important difference between the use of drop-valves and slide-valves, in connection with liberating valve-gear; for in the one case the dash-pot is applied to arrest the valve itself and prevent it from striking on its seat, but in the other it is only required to prevent the concussion of the weight or spring that is used to close the valve. If the drop-valve, in order to prevent concussion, is made to fall slowly just as it approaches its seat, it is evident that there must be a certain amount of wire-drawing of the steam; whereas with the slide-valve the motion of the spring or weight which closes it is not arrested by the dash-pot till after the valve is closed and the steam completely cut off: hence while the cut-off with the slide-valve must be perfect, with the drop-valve it must at best be to a certain extent imperfect.

Regulating the speed of steam engines by connecting the governor to vary the degree of expansion, instead of throttling the steam, was advocated, if not practised, by Watt, and many different arrangements have been invented and applied for effecting this object. In the Corliss expansion gear the governor is connected to the clips used to liberate the steam valves, and according as the pressure of steam in the boiler or the load on the engine varies, the supply of steam to the cylinder is cut off at an earlier or later period of each stroke; so that the speed of the engine is kept uniform, without the addition of any throttle-valve in the steam pipe. While the steam valves are thus controlled by the governor, and caused to close at an earlier or later period of the stroke to suit the varying conditions of the steam pressure or load on the engine, the exhaust valves have an invariable motion, and are opened and closed at the same point of the stroke, whatever may be the degree of expansion.

The disconnecting valve-gear for working the steam valves, as originally introduced by Watt and applied for the purpose of opening or closing poppet-valves, is shown in Fig. 1, Plate 88. It was usual in this gear to communicate motion to the valves by a rod A called a plug-tree, attached to some moving part of the engine, generally to the beam; on this rod were fitted tappets B B, to open or close the valves when moving in one direction, and when moving in the opposite direction to trip or liberate the catches and allow the weights to act for either closing or opening the valves, as might be arranged. The drawing shows the plug-tree A with its tappets B B, the valve C, the catch D, and the curved lever E for tripping the catch, the weight F for closing the valve, and the dash-pot G for bringing the weight gradually to rest when dropped. All the details are rude and clumsy, but it can be seen that there is in this arrangement the germ, so to speak, of the Corliss expansion gear.

In Fig. 2, Plate 88, is shown the arrangement of gear employed in the earlier Corliss engines in America for actuating the steam valves; and the contrivance used for tripping or liberating the catch, in connection with a governor, to produce the sudden closing of the valves. In this arrangement a weight H was used, attached to a lever on the valve-spindle I, to supply the external force for closing the valve when the catch K was liberated, the weight falling in a dash-pot similar to that in Watt's gear. This plan was improved several years ago by Mr. Corliss, who then introduced an arrangement in which the catches push the valves open instead of pulling them, and the valves are closed by long blade-springs fitted to vibrating levers. The tripping of the catch is effected by curving up the back end at K, and this end when moving forwards comes into contact with a plate L, which is acted on by a rod M connected with the governor; the rod M carries an incline, which raises or lowers the plate L according to the changes in position of the governor balls, so that when the plate is lowered by the governor balls flying out in consequence of excess of speed, the catch K is tripped sooner, and reduces the supply of steam to the engine by cutting off the steam earlier. A few engines fitted with this arrangement of gear were made in this country some years ago, but the plan appears to have since fallen into disuse.

The present improved construction of the Corliss engine is shown in Fig. 3, Plate 89, which is a side elevation of the cylinder and valve-gear of a small horizontal engine made by Messrs. Hick Hargreaves and Co. of Bolton for the Royal Arsenal at Woolwich, from designs by the writer. This engine, which has 12 inch cylinder and 2 foot stroke, works at 100 revolutions per minute. The cylinder is shown in transverse section in Fig. 4, Plate 90, and in longitudinal section in Fig. 5. The steam valves AA are placed on the top of the cylinder, and the exhaust valves BB at the bottom, separate pipes leading from them at each end of the cylinder. The steam valves are closed by a spring dash-pot CC, which pulls upon each valve-rod as it is drawn out; and the liberating gear consists of a pair of side spring-clips DD, which are released by the rocking of a double toe-lever EE, and then allow the steam valve to be closed by the action of the spring: the spring-clips and toe-lever, and the valve-gear generally, are similar to those afterwards described in the Saltaire engines. The valves are cylindrical on the face, being similar in action to ordinary slide-valves, but working upon a cylindrical instead of a flat face; the valve face is a longitudinal segment of a cylinder, having recesses on its inner side, into which drop the projecting arms of the valve spindle, so that the valve is moved by the partial rotation of the spindle in opposite directions alternately. The pressure of the steam on the valves tends to press them up to the face, only when the ports are closed; so that when the ports are opened, the valves move with practically no friction from the steam pressure, and thus the pull required to close the steam valves is small, and is practically independent of the pressure of the steam.

The cylinder is steam-jacketted both on the body and on the ends; and an improvement in the construction of these cylinders has recently been introduced by the writer, considerable trouble having been experienced in getting the jacketted cylinders sufficiently hard when cast in one piece, on account of the risk from cracking if cast with hard metal, and also in consequence of the annealing process that takes place during the cooling of the castings. The improvement consists in making the cylinder and valve-chest in four distinct pieces, with flanged face-joints F F to connect all together, as shown in Fig. 5. The cylinder and the steam-jacket are two concentric castings, fitting one inside the other, with a flange F F upon the jacket only; and a separate casting at each end forms the valve-chests above and below the cylinder, with a ring connecting the two valve-chests; the end of the cylinder is fitted into this ring, and the cylinder cover is fixed upon it, all the fitting surfaces being turned and bored. The separate castings are thus rendered quite simple, and can be made of any degree of hardness without risk; while the flanged face-joints provide security against leakage, much better than if the inner cylinder were simply let in, with slip joints parallel to its bore. A saving of time in making can also be effected, as the work on the separate pieces can be proceeded with in several machines at the same time.

Figs. 6 and 7, Plates 91 and 92, show a front and side elevation of one of the new cylinders with the improved Corliss expansion gear that have recently been erected at Saltaire by Messrs. Hick Hargreaves and Co. from designs by the writer. The engines are beam engines coupled together, with 50 inch cylinders and 7 foot stroke, working at 30 revolutions per minute. There are two pairs of engines to be replaced, four cylinders in all, and the new cylinders have been put in place and now completed for one pair, and are the same size; the previous cylinders had double-beat valves actuated by a cam motion. Figs. 8, 9, and 10, Plates 93 and 94, are vertical and horizontal sections of one of the cylinders, showing the valves. The cylinders and cylinder covers are steam-jacketted; and the valve chambers are cast with the cylinders. The steam valves C C are in front and the exhaust valves D D at the back of the cylinder, and the valve-gear is placed on the sides of the cylinders between each pair of engines. The steam and exhaust passages E E are cast separate from the cylinder, and provided with expansion joints F F, shown in section in Fig. 8. The valves are cylindrical on the face, similar in construction to those of the Woolwich engine previously described. All the four valves are opened by the eccentric rod T, Fig. 7, acting on an oscillating disc U, to which the four valves are connected by rods; the exhaust valves D D are also closed by the same means, but the steam valves C C are released, and are closed by an air-spring P. The stop-valve G in the steam passage is similar in make to the steam valves, and is opened by a worm and wormwheel to regulate the supply of steam; but it can be closed suddenly on any emergency by means of the lever handle H, which is keyed upon the valve spindle and is connected to the wormwheel by a detent that can be instantly disengaged, the wormwheel being loose upon the valve spindle. A small auxiliary conical stop-valve I opened by a screw handle is employed for turning on the steam gradually at starting, to relieve the pressure on the main stop-valve G.

The construction of the liberating valve-rod introduced by Mr. Spencer and the writer, for the disengaging gear to release the steam valves, is shown in Figs. 11, 12, and 13, Plate 95. The valve-rod is divided into two portions, one sliding steadily within the other at the cylindrical part A A; and the two are held together by the pair of spring-clips B B fixed on one portion, which rest on corresponding shoulders C C on the other portion of the valve-rod. The clips are released by the double toe-lever D, which rocks upon a transverse centre pin, and is shown in its two extreme positions in Figs. 11 and 12; the outer end K of the arm of the toe-lever being held by the rod L shown in the general drawing Fig. 7, the toe-lever D is made to rock in each stroke of the valve-rod, and the particular point of the stroke at which the toe-lever reaches its extreme position and disengages the spring-clips B B is determined by the position of the end K of the toe-lever arm, which is not stationary, but is acted on direct by the governor through the rod L. By this means all changes in position of the governor balls produce corresponding changes at the same time in the position of the fulcrum upon which the toe-lever acts, causing the release of the spring-clips to be earlier or later in the stroke according as the speed of the governor is greater or less than the correct rate, and thus regulating the engine by cutting off the steam earlier or later accordingly. The disengaging rods L L from the two steam valves are coupled together by a pair of toothed segments M M, shown in Fig. 7 and also in the enlarged drawing Fig. 14, Plate 96; and the rod N, Fig. 7, connects these with the governor. The spring-clips B B fall upon leather faces O O, to prevent any blow in closing; and the engaging edges of the clips and the shoulders are hardened steel faces let in and readily renewable.

The air-spring dash-pot P for this gear, Fig. 7, is shown enlarged in Fig. 14, Plate 96, one half in section. It consists of two cylinders, one within the other; the large cylinder has a loose-fitting piston R R, and the small cylinder a trunk piston S S fitted with metallic packing; the underside of this trunk piston is in connection with the condenser. The pressure of the atmosphere is therefore constantly pressing the small piston in, and this forms the spring for instantly closing the steam valve when liberated from the clip-rod; the large piston R is coupled to the small one S, and acts as a dash-pot to prevent concussion in closing the steam valve, as the air below the loose-fitting large piston R has to be driven out at the moment of closing the valve.

The double-clip gear, as far as experience goes, works with satisfaction, and is reliable and effective up to the speed of 100 to 120 revolutions per minute; and it could be worked at speeds considerably greater. More than sixty land engines, most of them of large size, are now at work in this country fitted with this gear, and many of these have been at work for several years, giving great satisfaction both in economy of fuel and regularity of speed; a considerable number of the engines have also been made and sent abroad. These engines have also been applied to steamers, and their use is rapidly extending for marine purposes. The arrangement of the valves and gear makes them easy of access either for inspection or repair; and from the number of engines satisfactorily at work it has been proved that with good workmanship the valves and gear can be kept in order at a very trifling expense.

The consumption of fuel with these engines is about 2½ lbs. of coal per indicated horse power per hour, which includes all the coal used for raising steam or banking fires. Indicator figures taken from the Saltaire engines are given in Figs. 15 and 16, Plate 97.

In conclusion the writer desires to add, with reference to the alterations of the Saltaire engines, that he was aided in the preparation of the designs by many valuable suggestions from Mr. George Salt, through whose kindness the members of the Institution will have an opportunity of seeing the engines at work on the present occasion.

Mr. **Inglis** showed a specimen of the spring-clip liberating gear as used in the Corliss engines at Saltaire.

Mr. W. M. **Neilson** enquired in reference to the valves of the Corliss engine, whether there was any provision for keeping them up to the face of the ports, as they worked up a curved surface; and whether any difficulty was experienced in making up the wear of the valve faces.

Mr. **Inglis** replied that the valve face was simply a portion of a cylinder moving round upon a cylindrical surface a short distance backwards and forwards, and was just similar in action to an ordinary flat slide-valve moving upon a flat surface; and it was kept up to the face of the port in the same way, simply by the pressure of the steam. The valves were of cast iron, and the wear was as uniform over the face as in an ordinary flat slide-valve; and they were driven by projecting arms on the central valve-spindle, which fitted easily into a recess on the back of the valve, leaving the valve resting free upon the port face.

Mr. F. J. **Bramwell** thought that the object to be aimed at in an engine was to combine economy in working with economy and simplicity in construction and repairs, but in reference to the engine described in the paper there appeared to him a serious complication of construction which would entail increased cost both in original construction and in repairs; and it did not seem to him, judging from the indicator diagrams shown, that the result arrived at was any greater economy of working than was obtained from well made engines of simple construction. The several contrivances that were combined in the engine had been tried before, as stated in the paper, such as the dash-pot, and the separate valves for steam and exhaust; and he remembered seeing the original Sickles cut-off valve-gear working in the river steamers of America. The special novelty in the present engine appeared to be the particular mode of effecting the liberation of the valve-gear in cutting off: this however was done by a most complicated piece of machinery, and he thought the question to be considered was whether any real advantage was gained to warrant this complication; especially when it was borne in mind that non-condensing engines were now seen at the agricultural shows which had only a single slide-valve with a cut-off slide at the back, and yet showed a consumption considerably below 3 lbs. of coal per effective horse power per hour, measured by the friction break. If such a high degree of economy could be practically obtained by so simple a construction, he thought the adoption of the complicated construction of the engine now described would be a retrograde step.

In the arrangement of the air-spring and dash-pot he thought there was a practical objection to the connection with the condenser of the engine, as any leakage of the trunk piston would allow air to pass into the condenser; while the great object now aimed at in condensing engines was to prevent entrance of air by every possible means, as for instance by the use of lantern brasses in the stuffing-boxes. He enquired what was the mode of starting the engine, before a vacuum was obtained in the condenser to supply the force required to close the valves.

Mr. E. A. **Cowper** said he quite agreed with the remarks of the last speaker; and considered an engine was wanted to do its work steadily, and that as good indicator figures as those now shown could be obtained with a proper slide-valve and expansion gear, without the objectionable complication of triggers and springs, which though certainly very ingenious were not in his opinion suitable for an engine.

Mr. B. **Walker** thought it was not possible with any cut-off valve on the back of an ordinary slide-valve to produce so good an indicator figure as those now exhibited from the Corliss engine, which showed a decided economy in working. He thought there was a great deal of merit in the arrangement of the valve-gear, but feared the construction involved too much complication and too many loose parts to allow of its becoming generally applicable.

Mr. C. W. **Siemens** considered that the indicator figures exhibited were certainly very perfect, and that the arrangement of valve-gear shown was capable of producing an exceptionally perfect cut-off and exhaust. Such expansion figures could not be produced by the link motion, and it had to be remembered that with the back cut-off slide the figure obtained was not equally correct for all degrees of expansion; but by the valve-gear now shown a very correct figure was obtained for all degrees up to a very high point of expansion. He quite agreed however with the opinions that had been expressed about the complication of the gear, and thought that several of the mechanical details were of an objectionable kind; but it must be borne in mind that the arrangement was intended as a means for obtaining a very perfect result, and should be considered with reference to that object.

Mr. C. E. **Amos** thought that in an engine which had to be kept in regular work, simplicity of construction was one of the most important considerations; and however beautiful and perfect the arrangement might be, all complications should be avoided, as complication in the working parts was liable to involve extra wear and tear and expense in working, which might practically outweigh the other advantages. The addition to the original cost of an engine, caused by complication of construction, was also a serious consideration.

Mr. T. **Hawksley** observed that the main value of the special contrivance now shown appeared to consist in getting by the use of springs a higher velocity in the closing of the valves than could otherwise be obtained; and then a higher speed of engine could be employed with a sufficiently quick action of the valves to give a good expansion. But though there might be some circumstances in which a high speed of engine was desirable, such as 400 feet per minute or more, he thought those cases would be comparatively few, and that the high speed would then be accompanied by an objectionable cost and loss from friction. The indicator figures shown from the engine were not sufficient he thought for forming an opinion as to the results, because an engine working with these disadvantages might exhibit quite as good a figure of expansion within the cylinder as an engine working without them; and consequently, though a good indicator figure was obtained from the engine, he feared the working effect would not be proportionate.

With regard to the determination of the effective horse power of an engine by means of a friction break, to which reference had been made, he thought the results obtained by that means were not to be relied upon for accuracy; for he had known instances of a large amount of error in the results obtained by employing a friction break as the measure of the power given off by a steam engine. A remarkable case of a similar nature was the measurement of the power obtained from turbines, the performance of which had been estimated by the use of a friction break to amount to 80 per cent. of the total power in the water expended, and in one case to even as much as 90 per cent.; but in fact the theoretical limit of the power that could be obtained from an absolutely perfect turbine was only 60 to 70 per cent., on account of the power unavoidably left in the discharged water flowing from the machine. He thought therefore that the very high results which had been stated to be obtained from agricultural engines by measurement with the friction break would be found to require a considerable correction, on account of error involved in the use of the friction break for this purpose.

Mr. C. E. Amos said he had had long experience in the use of friction breaks for measuring power transmitted, and was satisfied that when properly constructed their results were fully to be relied upon. One of the most striking illustrations of their accuracy was afforded in the laying of the Atlantic telegraph cable, where a dynamometer was used, with a friction break on Appold's improved plan, for measuring continuously the strain upon the cable whilst paying it out from the ship; and the action of this dynamometer was so delicate and sensitive that the slightest increase in the strain upon the cable at any moment was instantly indicated. The breaks were loaded to a definite point, at which the cable should slip; and it was always found to slip directly the strain reached that point. On another occasion in the Bay of Biscay some experiments were made with a similar cable dynamometer, and the depth of water calculated from the indicated strain upon the submerged cable was found to agree closely with the actual depth measured by sounding.

Mr. C. W. SIEMENS fully agreed in the correctness of the indications afforded by the friction break, and considered there could be no better illustration of the correctness of the principle than in the laying of submarine cables, where the safe management of the operation was entirely dependent upon the use of the break dynamometer. Also in the case of measuring the power given off by a steam engine, he considered the result obtained by calculation from the load sustained by a friction break driven by a shaft or belt from the engine must give the correct measure of the power transmitted by the shaft or belt, as all required deductions were thereby made for loss of power by friction and imperfections in the engine. In regard to the other application of the friction break that had been referred to, for measuring the power obtained by a turbine from moving water, the measure given by the friction break could not exceed the power actually given out; and in the case therefore that had been mentioned, where the measurement of the power obtained by turbines had appeared to exceed the theoretical limit possible, he thought the gross power residing in the water must have been under-estimated.

Mr. T. HAWKSLEY considered that the friction breaks used for measuring the power transmitted from engines were defective in the mode in which the power to be measured was taken off by the break. They were generally constructed on the plan that might be termed "dithering" breaks, in which the action was not steady and continuous, but the break was constantly jumping up and down, alternately biting and slipping, and was really doing no work at the moments of jumping off the wheel, although it was registering the full load throughout, and consequently indicating too high a result.

Mr. G. D. HUGHES believed that in several cases indicator figures which he had taken had as good an expansion curve as those now shown, with the steam cut off as early, and as good a vacuum line; and in these cases the engines had an ordinary slide-valve, with a cut-off slide on the back which was adjusted by the governor, controlling the speed of the engine without any throttle-valve. He thought it would be going back to adopt so complicated a construction for effecting the object as in the engine now shown; and considered the complexity would be found to involve a sacrifice in first cost and a great liability to get out of repair.

Mr. J. C. AMOS considered it was quite practicable to produce as good a diagram as those now exhibited, with a simple valve and a back cut-off slide; and the only advantage in the construction of engine now shown appeared to be the facility afforded for regulating the degree of expansion by the action of the governor, which notwithstanding the very numerous attempts that had been made could not be said to have been thoroughly accomplished yet with the ordinary slide-valve. The completeness with which this was effected in the plan now shown appeared to him the only good reason for departing from the simplicity of the ordinary double slide.

Mr. R. DOUGLAS remarked that he had had considerable experience in the manufacture and working of the Corliss engines, and could bear testimony to the fact of there not being that tendency to derangement of the working parts which seemed to be supposed; on the contrary the whole of the valve-gear was found to be very durable and satisfactory in working. He knew some of these engines had been in regular work for the last four years, running night and day, and their valves were still perfectly tight, and the steel catches of the liberating gear were now as square and sharp at their engaging edges as when first made, though they had been working the whole of the time; there was in fact only a very slight source of wear upon them, because at the moment of disengaging there was only the pull of the spring upon the catches that were released, and the valve was then open with no pressure upon it, and requiring consequently very little power to move it. He had fixed Corliss engines in many cases in the place of other engines, and had effected by the change a saving of one third in the consumption of fuel in all instances, and in some cases even more. It was very difficult however to make correct comparisons of engines in this respect, on account of the great variations in the conditions; but in another respect, namely the undeviating uniformity of speed, there was no question as to the advantage gained with the Corliss engine. In one instance of an ordinary engine driving a flax mill, where two thirds of the mill was driven from one cog-wheel, this wheel had got stripped on one occasion previously to the change of engine, and the result of the acceleration in speed of the engine in consequence of two thirds of the work being suddenly thrown off was that the threads in all the remaining spinning frames were broken; but after the Corliss engines were substituted, although a similar accident happened from the stripping of the teeth of the same cog-wheel, not a single thread was broken in the spinning frames, as the supply of steam to the engines was instantly diminished to correspond with the diminished load. He did not know how such a regulation of the speed could be accomplished by any arrangement of a cut-off slide working on the back of another; but in the Corliss engine the steam-valves were completely thrown out of gear at every stroke, so that when the engine was making 30 revolutions per minute the steam supply was regulated 60 times in a minute, which gave a great nicety in regulating the speed of the engine.

Mr. INGLIS said that the valve-gear in the Corliss engines, although appearing complicated, did not really involve any practical objections in working, as the working parts were very durable and were subjected to very little wear. There had never been any trouble with any of these engines, although more than sixty of them were already in use in this country; and they had given such entire satisfaction in their working that there were now nearly twenty more of them in progress. A decided economy in consumption of fuel was found to be effected by these engines, where a comparison with other engines working under the same circumstances could be made. At

Woolwich Arsenal, where four of the Corliss engines were in use, a careful trial had been made during three months' working, and the result was found to be considerably in their favour in cost of working; their total average consumption during that time was 2½ lbs. of coal per indicated horse power per hour, with a steam pressure of 45 lbs. per inch. The general working of other engines would be found he thought to average nearly 5 lbs. per indicated horse power per hour, and he believed more than half of the engines included in the Manchester Boiler Association were fully up to that amount or above it. The pair of Corliss engines at Saltaire, which had now been working about two months, would afford a good opportunity for comparison of results with the original pair of engines continuing to work alongside of them under exactly similar circumstances, the only difference being that the cylinders were not steam-jacketted in the original engines.

In reference to the enquiry about the arrangement for starting the Corliss engine, before a vacuum was obtained in the condenser for supplying the spring to close the steam valves in cutting off, the valve-gear was arranged not to be liberated at all when the governor was down in its lowest position; so that at starting the engine the valve continued connected to the gear throughout the stroke, and consequently did not require the air-spring for closing it; but by the time the speed was increased sufficiently for bringing the governor into action and liberating the valve at each stroke, a vacuum had been obtained in the condenser so as to effect the closing movement by the air-spring.

Mr. H. **Woods** thought that a consumption of 5 lbs. per horse power per hour was too high a figure to be taken for general comparison, and that such a consumption could apply only to defective engines.

Mr. T. **Hawksley** did not understand how any great difference in consumption could arise in really good engines, under the same circumstances of good condition, if the degree of cut-off were the same in both the engines compared; for when the steam was once shut into the cylinder, its expansion would be the same in both cases, and any difference in the indicator figures would be chiefly due to condensation in the cylinder from the want of a steam jacket, which however could not amount he thought to more than an additional consumption of ½ lb. of coal per horse power per hour. Any greater difference he thought must really be due to the two engines compared not being in equally good working condition; but if the two engines had their cylinders equally warmed by steam jackets, the same expansion curve in the indicator figure would be obtained from both, if the steam was cut off at the same point and at the same pressure in both, although one might be a good engine and the other a bad one.

Mr. INGLIS observed that the expansion curve was affected materially by the amount of clearance at the ends of the cylinder, which in some engines amounted to a considerable proportion of the contents of the cylinder; but in the Corliss engines the clearance was reduced to an unusually small proportion by the arrangement of the valves, and in the Saltaire engines it amounted to only 2½ per cent. of the capacity of the stroke, including both the clearance and the contents of the ports, whereas in other makes of engines it was usually considerably more. The area of the exhaust passages in the Saltaire engines was 1-10th of the cylinder, and the steam passages 1-16th. The sharpness of cut-off in the Corliss valve-gear prevented the loss that was generally shown in an indicator diagram from the rounding off of the top of the figure; and the uniformity in the action of the valve-gear prevented the inequality that was generally found in other cases in the supply of steam at the two ends of the cylinder. There was also a great advantage in working entirely from the governor, so as to regulate the speed of the engine by the degree of expansion, thereby getting always the full steam pressure in the cylinder up to the point of cut-off, instead of wire-drawing the steam pressure by contracting the opening of a throttle-valve in the steam pipe.

The CHAIRMAN remarked that the subject was one of great practical interest and importance, and required close investigation, both as to the real economy in working of the new engines and as to the actual wear and tear attending the complication in their construction. There would be an unusually good opportunity for comparison between the new engines at Saltaire and the original engines, provided one pair were retained for a few months to work against the other pair that was altered; it would then be seen what advantage, if any, was derived from the change. The original engines, which had been made at his own works, had been at work about twelve years and had given great satisfaction. They were plain single-cylinder beam engines, with double-beat valves worked by a cam motion adjustable to different degrees of expansion. Improvement in the construction of steam engines was certainly a subject of great practical importance, and it was desirable that any improvement such as the one before the meeting should be thoroughly investigated; and the members would have a good opportunity, through the kindness of Mr. Salt, of examining both the new and the old engines at work at Saltaire that afternoon.

He moved a vote of thanks to Mr. Inglis for his paper, which was passed.

The following paper was then read:—

ON THE MACHINERY FOR WEAVING BRUSSELS CARPET BY POWER.

By Mr. WILLIAM WEILD, of Manchester.

In Carpets and other pile fabrics, there are interwoven, between the threads of the ordinary plain fabric forming the body or back of the carpet, other threads, generally of a different material, which are interwoven in such a manner as to form a terry, looped, or pile surface. In the actual weaving there is therefore little difference between pile fabrics and plain or jacquard fabrics, the additional mechanism required for the pile fabrics being only such as will form the pile threads into loops on the surface of the fabric during the process of weaving. The substitution of self-acting machinery for weaving carpets and other pile fabrics, in place of the previous hand labour, has occupied the particular attention of machinists for more than twenty-five years, and many arrangements have been invented for effecting this object; but it was only between 1851 and 1856 that machinery for the purpose was so far perfected as to be commercially successful.

There are two classes of pile fabrics: those in which the pile is formed by the "weft" (the threads passing crossways of the piece); and those in which it is formed by the "warp" (the threads passing lengthways of the piece): but it is only the latter class that is referred to in the present paper. Various methods of weaving warp-pile fabrics have been proposed, some of which are in use at the present time. Hat-plush or velvet is manufactured by weaving two pieces at the same time, face to face, the pile warp being bound alternately in each piece; and the two pieces are afterwards separated by cutting the connecting pile, so that each piece contains half of the pile warp. Terry or looped fabrics have been manufactured in various ways; but the method most usually adopted for forming the loops of the pile is by means of wires placed in the "shed," that is the opening between the threads through which the wire passes across the fabric. This plan is practised in weaving by hand, and is generally admitted to be the best method yet known for making a good and regular terry or looped pile-fabric. The wire is introduced into the shed between the pile threads and the body warp, so that when the pile threads are afterwards bound down again in the body of the fabric they form loops over the wire, which is subsequently withdrawn from the fabric. The object aimed at in most of the inventions for weaving pile fabrics by power with the use of wires has been to combine mechanism for inserting and withdrawing the wires with the mechanism of the ordinary power loom employed for weaving either plain or jacquard patterns.

Three descriptions of warp-pile fabrics are manufactured, which are known as Tapestry carpet, Brussels carpet, and Velvet or Cut-pile carpet, the construction of which is illustrated by the diagrams Figs. 12 to 14, Plate 104.

In Fig. 12 is shown a longitudinal section of a Tapestry carpet, with a shed formed for the new wire A to be inserted. The body of the fabric is formed by the two sets of warp threads B B, which are generally linen threads; these are interwoven with the weft, the threads of the weft being seen in section in the diagram; and in addition there is generally a warp of thick soft threads C, for the purpose of giving sufficient thickness and substance to the fabric. In this construction of carpet these thick threads C remain always in the middle of the fabric, and the weft passes above and below them across the carpet, as shown in the diagram. The pile threads D never descend below the thick threads C, and consequently never appear at the back of the carpet; and in the operation of weaving the whole number of the pile threads are raised and lowered simultaneously; when raised they form the shed for the new wire A to be inserted beneath them, as shown in Fig. 12. Where there are designs in colour upon a tapestry carpet, they are produced by each separate pile thread being made parti-coloured and arranged in such a manner that when woven over the wires a pattern is produced by plain weaving.

In Fig. 13, Plate 104, is shown a longitudinal section of a Brussels carpet, with a shed open for the new wire A to be inserted. Here the body warp B is the same as for tapestry carpet, but there are five times as many pile threads D D as in tapestry carpet, and not more than one-fifth of the whole number of pile threads are raised simultaneously to form the shed for inserting the wire; the other four-fifths of the pile threads take the position of the thickening warp C in tapestry carpet. Some of the pile threads are only required to ascend and form loops at long intervals in the pattern, and the consumption of the same thread varies at different times according to the requirements of the pattern. Consequently a greater length of some pile threads is necessary than of others, and each pile thread therefore has here to be placed upon a separate bobbin; whereas for tapestry carpet all the pile threads are wound off a single long roller. The design in Brussels carpet is formed by the jacquard, each pile thread being of some particular colour throughout from end to end; and the jacquard draws up those threads which are of the colour required to produce the pattern.

In Fig. 14, Plate 104, is shown a longitudinal section of a Velvet or Cut-pile carpet. This is similar in construction to Brussels carpet, except that two shoots of weft are used to tie down each loop of the pile more securely; and the pile threads being woven over wires of deep section, as shown exaggerated in the diagram, the loops are afterwards cut open in withdrawing the wires, so as to form the velvet surface, as shown at E. The wires used for weaving velvet pile are shown full size in the side and edge views, Fig. 15, a knife F being formed at the outer end of each wire for the purpose of cutting open the loops in withdrawing the wire.

In Figs. 16 to 18, Plate 104, are shown diagrams of the three sheds required in weaving Brussels carpet. The shed in Fig. 16 is one for the shuttle, where all the pile threads D have been lifted as well as half of the body warp B, the other half of the body warp B being down; and the shuttle G then puts in the bottom shoot of weft that comes upon the back of the fabric. The shed shown in Fig. 17 is the next one formed, and is also for the shuttle, all the pile threads D being down, while the two halves of the body warp B B remain in the same positions as previously; and the shuttle G then puts in the top shoot of weft, which ties down the loops formed upon the last wire inserted. The third shed, shown in Fig. 18, is for inserting the next wire A; here all the body warp threads B and pile threads D are down, except those pile threads that are lifted by the jacquard, which are to form the loops upon the new wire.

In the first attempt to apply self-acting machinery for working the wires, they were drawn out one by one as required from a bundle of wires, and were carried through the shed by a pair of nippers fixed at the end of a reciprocating rod; and after having been woven into the fabric and then withdrawn from the loops, the wires were returned by hand to the bundle. Next the whole operation was rendered self-acting, by dropping wires successively from a hopper into a longitudinal groove in a rod, which was pushed through the shed in guides, and was then caused to make a half revolution by means of a screw incline on the rod, so as to drop the wire into its place in the shed; and the wires were withdrawn successively from the fabric by reciprocating nippers, and carried up again into the hopper by endless chains. Afterwards an improvement was made by placing the wires singly in a trough, from which each in succession was pushed into the shed; and the wires were made with a hook at the back end of each, by means of which each was drawn out of the fabric successively by an endless chain, and was then transferred to the feeding trough for insertion again into the shed.

In the early application of machinery for working the wires, it was assumed that for wide fabrics, such as carpets, the wire could not be passed through the shed without being supported in its passage, on account of the deflection of its free extremity; various contrivances were therefore employed for supporting the wire as it passed through the shed, the wire being pushed from a trough used as a guide. It has since been found practicable however for the wires used in carpet weaving to be introduced without having supports in the shed; and this is done in the loom now extensively employed by Messrs. Crossley of Halifax, which comprises the important improvements of the late Mr. Collier. In this loom a horizontal slide works in a long guide which is attached to arms fixed on a horizontal shaft below, so that the guide and the slide can be oscillated longitudinally in the loom between the positions for drawing the wire out of the fabric and inserting it again in the shed; the slide is made with a holder for holding the end of the wire. For drawing the wire out of the fabric a sliding hook is used, which is actuated by a crank; this hook takes hold of the bow on the end of the wire, and by the time it has drawn the wire nearly out of the fabric, the holder on the inserting slide has arrived opposite to it, and the end of the wire is jammed into the holder by the hook; the movement of the hook in the outward direction then ceases, but the sliding holder still continues its back movement until the wire is clear of the fabric and hook. When drawn out of the fabric the free end of the wire is received in a directing fork, which has an oscillating movement imparted to it longitudinally, corresponding with that of the oscillating frame carrying the inserting slide. The directing fork and the inserting slide then together carry the wire to the position for insertion into the shed; and during the time it is being inserted, they still continue their oscillating movement towards the wider part of the shed, until the wire is inserted to the full length. The inserting slide stands still while the wire is beaten up by the reed and bound in by the pile threads; after which it begins to slide outwards, releasing its hold of the wire, and at the same time the oscillating frame moves towards the point where the next wire is being withdrawn from the fabric, so that the sliding holder may be ready to receive the wire from the drawing-out hook in the manner already described. These movements are repeated for each wire inserted.

The arrangements previously referred to for working the wires in weaving pile fabrics have been for working a number of loose wires, where there are always ten to thirty wires or more remaining at the same time in the fabric during its manufacture: this method of working the wires is therefore known as the "loose wire" system. There is however another method of working the wires, called the "fast wire" system; and the first plan for working the wires on this system by self-acting arrangements in hand looms for weaving narrow fabrics was invented in 1842 by Mr. Thompson of Coventry. Two wires are here used, one on each side of the fabric, and fixed at the outer end to arms or holders; these arms have successive movements whereby they withdraw each wire alternately from the fabric, then move it to the widest part of the shed and insert it in the shed, and then bring it back to the "fell" or point of beat up. At present however it is believed very few, if any, of this class of looms are employed. Manufacturers in general have an objection to looms in which only two wires are used, being of opinion that a good carpet pile fabric cannot be produced by that plan; and it may be presumed that this objection has some foundation, otherwise the improvers of this class of looms would not have departed from the simplicity of the two-wire loom by adding arrangements for working four wires, which render such looms very complex.

In the methods of working the wires on the loose-wire system there is considerable uncertainty in the mechanism, although it is probable that the various plans which have been described may all have been intended originally to act at very slow speeds; but it is rapid motion that developes the uncertainty and incorrect operation of the mechanism. In the improved loom about to be described however, which has been invented by the writer and made by Messrs. Sharp Stewart and Co., the previous defects are now so greatly diminished that the uncertainty of action may be considered to be entirely obviated. The new method of working the wires combines the advantages of both the systems previously described, namely the advantage of good quality in the fabric in consequence of using a number of wires, and also the advantage of the certainty of action belonging to the fast-wire loom, since the wires are never released or detached from the mechanism by which they are actuated. The movements of the wires are practically reduced to a simple reciprocation, as they may be considered to be virtually fixed in position.

This construction of mechanism for working the wires is known as the "roller wire-motion," and is shown in Figs. 1 to 11, Plates

98 to 103, in the improved form that is extensively used at the present time. Fig. 1 is a sectional side elevation of a Brussels carpet loom, showing the creel frames for the five sets of pile bobbins, the jacquard, and some of the principal parts of the loom. Fig. 2 is a longitudinal section of the loom to a larger scale; and Fig. 3 is a front elevation.

At the middle of the framing of the loom is the crank shaft C, Fig. 2, which actuates the "slay swords" or pair of arms B B carrying the reed S and the shuttle race G, and vibrating upon a shaft at the lower part of the frame of the loom: the position which the slay occupies at the "fell" of the fabric, when it has beaten up the weft or the wire, is shown by the dotted lines in Fig. 2. The cam shaft D is placed under the crank shaft C, and carries at one end the tappets from which the healds E are worked, Fig. 2, for lifting and depressing the threads forming the body warp of the carpet. Upon the cam shaft D are also fixed two arms F F carrying rollers, Fig. 3, which actuate through bell-crank levers the two picking arms H H; the free ends of these arms working through a slot in the shuttle-box give motion to the picker or shuttle. The comberboard I, Fig. 1, is carried by a pair of vertical sliding rods, one on each side of the loom, and receives the required up and down movement by means of a lever from a cam on the cam shaft D; the weight to be lifted by the comberboard is partly counterbalanced by weights on the tail end of the lever. The comberboard has as many holes in it as there are pile threads, and the cords J, Fig. 2, which actuate the pile threads pass through these holes, one through each; a knot which will not pass through the hole is made upon each cord a little above the comberboard, so that when the board is lifted all the pile threads are lifted together to form the shed for the bottom weft which crosses underneath the pile warp. The weights K suspended to the cords bring down each cord and its pile thread after it has been lifted. The jacquard L, Fig. 1, which is of ordinary construction, is actuated by a cam upon the cam shaft D; and the trap board lifts the successive selections of pile threads intended to form the loops upon the wires.

The five sets of pile threads are supplied from creels carried in the five creel frames M M, Fig. 1, each thread being wound on a separate creel. A plan of one of the creel frames is shown to a larger scale in Fig. 4, Plate 101; and a side elevation, partly section, in Fig. 5. A weight for giving tension to the thread is hung upon each thread, between the creel and a wire over which the thread passes, as shown in Fig. 5. The body warp threads are placed upon the two long rollers N N at the end of the loom, Figs. 1 and 2, half the entire number of threads being upon each roller; and the threads are drawn off each roller over a smaller vibrating roller, which allows them to give way to the working of the healds E. The carpet newly woven is received upon a plate O, Fig. 2, extending across the loom, and then passes over a guide roller to the taking-up roller P, which is made of wood and studded with short spikes, so as to drag the carpet along as fast as it is woven, and deliver it to be wound upon the receiving roller Q placed below. This last roller is rotated by a ratchet-wheel and paul, which is actuated by a spring attached to one of the slay swords B; the use of a spring for this purpose prevents the possibility of winding up the carpet any faster than it is delivered by the spiked roller P.

The Roller Wire-Motion, or mechanism for working the wires, is fixed on one side of the loom, as shown at R R in the front elevation Fig. 3, Plate 100; and the construction of the mechanism is shown to a larger scale in Figs. 8 to 11, Plates 102 and 103. Figs. 8 and 9 are a front elevation and plan of the wire motion, showing one of the wires A in the act of being inserted into the shed of the fabric; and the plan shows a portion of the carpet already woven, and the reed S for beating up the weft or the wire. Fig. 10 is a transverse section, half full size, of the roller R in its casing E, with the slide T for inserting and withdrawing the wires; and Fig. 11 is an end elevation showing the arrangement for rotating the roller of the wire motion. Figs. 6 and 7, Plate 101, show a full-size side view and edge view of one of the wires.

The roller R and its casing E, Figs. 8 and 9, Plate 102, are rather longer than the width of the carpet to be woven; and the upper part of the casing E is cut away through the extent of one sixth of the circumference of the roller, as shown in Fig. 10. Six longitudinal grooves are formed in the surface of the roller, of a width and depth corresponding to the diameter of the wires used. The roller in its casing is placed horizontally at one side of the loom, with its end about 9 inches from the edge of the carpet, and with the upper surface of the roller level and parallel with the "fell" of the fabric, as shown in Figs. 8 and 9. At that end of the casing nearest to the carpet, a recess is formed between the end of the roller R and a hoop I concentric with the roller; and in this recess, which extends through one sixth of the circumference of the roller, the heads of the wires are held when inserted in the fabric, as shown in the plan, Fig. 9, each wire having a head of the form shown in Fig. 6. The hoop I keeps the heads of the wires down in their places when inserted into the fabric, and prevents the wires from being pushed too far into the carpet; while the end of the roller prevents them from being withdrawn before the proper time. A projection upon the end of a spring J attached to the side of the casing keeps the heads of the wires erect, pressing them against each other and against the end of the recess, during the whole time that the wires remain inserted in the carpet. At the opposite or outer end of the roller R there is a projecting collar formed all round the roller, between the end of the casing E and a hoop carried by a bracket; and this collar has six grooves in it to receive the heads of the wires, so as to keep the heads in their correct radial position while being carried round by the roller in the direction shown by the arrow in Fig. 10. When the roller is stationary, two of its six grooves are opposite the two extreme wires in the recess I, Fig. 9: one being opposite the wire last inserted into the fabric, and the other opposite the wire next to be withdrawn from the carpet. The other four grooves have each a wire lying in them, as shown in Fig. 10, so that each time the roller is turned through one sixth of a revolution, one wire is brought round to the place for insertion into the shed of the fabric, and the wire last withdrawn from the carpet is carried away.

On the front of the casing E a slide-way is formed parallel to the axis of the roller R, Figs. 8 to 10, upon which is fitted a slide T, carrying the finger U for inserting the new wire, and the paul V for withdrawing the last wire. The finger U is hinged upon the slide T by a spring joint, as shown in Fig. 10, so as to be held steady when either up or down. When down, as in Fig. 10, it slides against the inserting edge of the casing E; and a recess in the extremity of the finger fits over the head of the wire that is being inserted, so that as the slide T traverses inwards towards the carpet, the finger U pushes the wire forwards into the shed, holding it down all the time in the groove of the roller. When the slide arrives at the inner end of its traverse, nearest to the carpet, the paul V is tripped up by the head of the wire to be withdrawn, and drops on the inner side of the head, and the wire is then withdrawn from the carpet by the paul during the outward traverse of the slide T. In order to prevent the wire while being withdrawn from getting out of the groove in the roller R, several curved fingers K K are used, jointed to the underside of the casing E; the ends of these fingers cover the groove which receives the wire withdrawn, as shown by the dotted lines in Fig. 10, and each finger is pressed down upon the roller by a spring acting against the side of the hole through which the finger passes in the casing E. These fingers have to be lifted out of the way successively in order to allow the head of the wire to pass; and this is done by a double incline L upon the bottom of the slide T, which acts upon the projecting tail of each finger in succession during the traverse of the slide.

The slide T receives its traversing motion from a rope X, Figs. 8 and 9, which is secured in a hole in the slide by a block and set screws, Fig. 10; this rope passes over guide pulleys at the ends of the roller casing E, and then to the pulley Y, Fig. 3, to which the two ends of the rope are secured. The shaft of the pulley Y carries a pinion gearing with the toothed sector W, which is centred at the top in the framing of the loom, and is worked backwards and forwards by a drum cam upon the cam shaft D, Fig. 3. This cam is shaped to produce a quick forward traverse of the slide T, so as to insert the wire quickly while the shed is held open for it; but the cam gives a slower backward traverse to the slide, so as to withdraw the wire slowly, having more time to do this in, as a wire is inserted only at every third shed.

After each wire has been inserted in the fabric, the wire roller R, Fig. 10, is turned round through one sixth of a revolution in the direction of the arrow, by means of the mechanism shown in Fig. 11, Plate 103. The cam M, Figs. 3 and 11, on the end of the cam shaft D of the loom, gives motion to a lever oscillating upon a centre in the framing of the loom; and the other end of this lever has a forked paul jointed to it, which is kept pressed by a spring against the pins in the disc N secured upon the end of the wire roller R, Figs. 8 and 9; the extent of movement of the lever and paul is shown by the dotted lines in Fig. 11. The wire roller is held steady after each turn by a T piece sliding vertically, which is pressed upwards by a spring against the pins in the disc N, as shown in Fig. 11.

The wires lying in the grooves of the roller previous to insertion into the fabric project 2 or 3 inches beyond the inner end of the roller; and if the point of the wire went straight forwards, as pushed from the groove in the roller, it would be impossible to make it enter the shed correctly, as it would then be so close to the "fell" of the fabric or angle of the shed that the point of the wire would inevitably catch the threads forming the shed. The wire is consequently sprung or deflected upwards and to one side, as shown at A in Figs. 3, 8, and 9, by means of the short grooved guide Z, through which the wire passes as it is pushed out of the roller groove. The guide Z is fixed upon the top of a vertical rod, which is moved up and down by a lever actuated by a cam; and when the wire has been pushed nearly through the shed, the guide is lowered into the position shown by the dotted lines in Fig. 8, so as to be out of the way of the wire at the moment of its being beaten up by the reed; after which the guide is lifted again, so as to be ready for the insertion of the next wire. The springing of the wires by the guide in directing them into the shed might at first sight appear objectionable; but the amount of this bending does not exceed what they will recover by their own elasticity, and the experience of working during many years has proved it to be a great advantage, because the bending stiffens the wire and makes its point steadier whilst passing through the shed. Besides this, in consequence of the angle at which the guide causes the wire to enter the shed, the point of the wire comes into a wider part of the shed the further it passes through the shed; and thus, as the unsteadiness of the point of the wire increases with the greater length unsupported in the shed, more space is allowed for its vibration, without risk of its catching the threads forming the shed.

Owing to the position of the roller wire-motion at one side of the loom, the shuttle-box on that side has to be made detached from the slay B B, Figs. 2 and 3, and carried by separate "slay swords" which oscillate upon a shaft coinciding with the shaft for the slay B B. This loose shuttle-box is actuated by a cam upon the crank shaft C of the loom, which acts upon a roller in a rod jointed at one end to the shuttle-box; the other end of the rod is slotted to slide upon the crank shaft as a guide. The cam is shaped so as to actuate the loose shuttle-box in such a manner that it will come opposite to the slay B B and have a motion identical with it at the time the shuttle is passing across the shed.

This loom will weave 3 inches of carpet per minute, and as much as 47 yards has been woven in one day of ten hours, including stoppages. The average production per day of ten hours is 42 yards of carpet, which is an important increase over the production of the previous constructions of looms.

Mr. **Weild** exhibited a specimen of the roller wire-motion, showing its action, with samples of the different kinds of wires used.

Mr. C. W. **Siemens** enquired how long this motion had been in use in carpet looms.

Mr. **Weild** replied it had been at work for twelve years, and was now extensively used, having been found superior to the other plans both in the speed at which it could be worked, on account of the certainty of its action, and also because it was free from the liability of the wire missing its course when passed into the shed and getting its end pushed up through the warp. The wires were held firmly in the grooves of the roller by the series of curved fingers, which were successively lifted and dropped again in the passage of the slide by the inclined plane upon the slide; and whilst the wire was being passed into the shed it was held firmly all the time at the back end by the spring finger of the slide, and the free end of the wire was steadied by being sprung on one side by the grooved guide, which stiffened the wire at the time by the elastic strain put upon it; by this means the free end was so well steadied as to prevent the risk that occurred in other looms of its catching the warp threads, although this loom was worked at a higher speed. The side springing of the wires did not strain or bend them permanently, as they were of hard steel and very carefully made.

Mr. W. RICHARDSON asked what was the difference of speed, and how many yards per day could be woven by hand looms.

Mr. WEILD replied that this loom put in 27 wires per minute as compared with 21 per minute in the other looms; but in hand weaving the speed was only about 3 to 4 wires per minute.

Mr. W. RICHARDSON enquired whether the roller motion laid the wires in quite as regularly as hand work; and whether the same motion was suited to the work of all looms.

Mr. WEILD replied that the regularity of the machine work was perfect in laying the wires and beating them up; and one pattern of machine suited all looms, because there was one standard make for all Brussels carpets, namely 8 wires per inch of length, and 27 inches width of carpet. The difference in the work involved in the carpets was in the number of coloured threads used in the pile warp for forming the pattern, and in the best carpets these amounted to the immense number of 1300 threads, all of which had to be brought up to the surface in turn and all kept in order. About one fifth of the whole number had to be picked up by the jacquard at each insertion of a wire, to ensure the wire being completely covered all across the fabric. There were also the threads of the body warp to be added, for forming the foundation of the fabric; and these raised the total number of threads to about 1700 in the best carpets, each one of which had to be passed through an eye in a separate cord, so as to be picked up individually whenever required.

The CHAIRMAN asked what attendance a loom required in working.

Mr. WEILD replied that one man attended to one loom, and a boy attended to the creels of two looms, his business being to change the spools of warp threads as they became emptied.

The CHAIRMAN remarked that it was a very ingenious and interesting piece of machinery which had been described; and he moved a vote of thanks to Mr. Weild for his paper and the specimens exhibited, which was passed.

The CHAIRMAN proposed a vote of thanks, which was passed, to the Honorary Local Secretaries, Mr. John Fernie and Mr. W. E. Marshall, for the excellent arrangements they had made for the meeting of the Institution in Leeds; and also to the authorities of the Philosophical Hall for their kindness in granting the use of the Lecture Theatre for the purpose of the meeting; and to the several Railway Companies for the special facilities they had so kindly afforded to the Members for attending the Meeting in Leeds and the Excursions in connection with the meeting.

The Meeting then terminated.

In the afternoon an Excursion was made by the Members by special train to the Works of Messrs. Titus Salt, Sons, and Co., at Saltaire, where the new Corliss Engines were seen at work; and the Members were very handsomely entertained at the Works by Mr. George Salt, and returned to Leeds in the evening.

On Thursday, 30th July, the Members visited the Tingley Colliery, where the two different Coal-Cutting Machines described at the Meeting—the Pick and the Straight-action Machine—were both seen at work in the pit. The Shale Oil Works and Brick Machinery at Tingley and the new Blast Furnaces at Ardsley, belonging to the West Yorkshire Coal and Iron Company, were also shown to the Members.

The Members also visited the Steam Plough and Locomotive Works of Messrs. John Fowler and Co. in Leeds, where the new Wire-Rope Travelling Crane described at the Meeting was seen at work.

On Friday, 31st July, an Excursion was made by the Members by special train to Scarborough, visiting at York on the way the new Lendal Iron Bridge and the Minster; and they were invited to Dinner in the evening by the Local Committee at the Grand Hotel, Scarborough, in celebration of the Leeds Meeting of the Institution.

PROCEEDINGS.

5 November, 1868.

The General Meeting of the Members was held in the Lecture Theatre of the Midland Institute, Birmingham, on Thursday, 5th November, 1868; **Frederick J. Bramwell**, Esq., Vice-President, in the Chair.

The Minutes of the last Meeting were read and confirmed.

The Chairman announced that the President, Vice-Presidents, and five Members of the Council in rotation, would go out of office in the ensuing year, according to the rules of the Institution; and that at the present meeting the Council and Officers were to be nominated for the election at the Anniversary Meeting.

The following Members were nominated by the meeting for the election at the Anniversary Meeting:—

PRESIDENT.

Sir William G. Armstrong,	Newcastle-on-Tyne.

VICE-PRESIDENTS.

(Six of the number to be elected.)

John Anderson,	Woolwich.
Frederick J. Bramwell,	London.
Edward A. Cowper,	London.
Thomas Hawksley,	London.
Sampson Lloyd,	Wednesbury.
W. Montgomerie Neilson,	Glasgow.
John Ramsbottom,	Crewe.
C. William Siemens,	London.
Charles P. Stewart,	Manchester.

COUNCIL.

(Five of the number to be elected.)

Alexander Allan,	Worcester.
Robert Broad,	Tipton.
John Fernie,	Leeds.
Sir Charles Fox,	London.
Edward Jones,	Birmingham.
William E. Marshall,	Leeds.
Walter May,	Birmingham.
John Robinson,	Manchester.
Francis W. Webb,	Bolton.
Percy G. B. Westmacott,	Newcastle-on-Tyne.
Richard Williams,	Wednesbury.

The Chairman announced that the Ballot Lists had been opened, and the following New Members were duly elected:—

MEMBERS.

William Coulson,	Durham.
Samuel Firth,	Leeds.
Henry Houldsworth Grierson,	Manchester.
John Heaton,	Nottingham.
William Shillito Hudswell,	Leeds.
George Frederick Lyndon,	Birmingham.
William Morris,	Chester-le-Street.
William Towndrow Stenson,	Coalville.

ASSOCIATE.

James Cordon,	Stoke-upon-Trent.

GRADUATES.

Frank Mappin,	Sheffield.
William Moor, Jun.,	Hetton.

A paper was then read "On the further utilisation of the Waste Gas from Blast Furnaces, and the Economy of Coke due to increased Capacity of Furnace," by Mr. Charles Cochrane, of Dudley; and the discussion was adjourned to the next meeting. (See Proceedings January 1869.)

The following paper was then read:—

ON AN IMPROVED FRICTION COUPLING AND BREAK, AND ITS APPLICATION TO HOISTS, WINDLASSES, AND SHAFTING, &c.

By Mr. THOMAS A. WESTON, of Birmingham.

The Frictional Apparatus forming the subject of the present paper has been successfully employed as a Clutch or Coupling and also as a Break. The applications already made are very varied, ranging upwards from the small friction bearings of toilet or swing glasses which yield a resistance of a few pounds only, to the "connector and break" of ships' windlasses for resisting a direct pull of thirty tons or more.

The apparatus consists of two series of friction discs, arranged alternately with each other upon a common axis, one series being carried by one shaft, and the other series connected to the other shaft or wheel which is required to be coupled with the first shaft. The discs on the first shaft cannot turn independently of it, but can slide lengthwise upon it towards or from each other: this series of discs are for convenience called the "shaft discs" in the following description. Arranged alternately with them are the discs of the other series, which have each a circular central opening sufficiently large to clear the shaft entirely; but at their outer edge they are slotted or made polygonal, or otherwise fitted in their outline to an external drum or cylinder containing them, so that they cannot rotate independently of the drum but may slide longitudinally within it. These discs are called for distinction the "intermediate discs;" and the drum containing them forms part of the spur wheel that is required to be connected to the shaft with a coupling or break action; or the drum is attached to a second shaft lying in line with the first, with which the second shaft is required to be coupled. So long as no longitudinal compression is applied to the discs, the shaft discs with the shaft carrying them are free to rotate independently of the intermediate discs and the drum containing them; but upon compressing the discs together longitudinally into frictional contact, the rotary motion of one series is either transmitted wholly to the other series, or is controlled or arrested by friction against the discs of the other series; and the double series of discs acts thus either as a coupling or as a break. The great advantage arising from the alternate arrangement of the discs is that the frictional effect of any pressure applied to couple them is repeated as many times as there are discs in the two series; that is, the number of all the discs is a constant multiplier for the friction produced between a single pair of the rubbing surfaces by any given pressure.

This principle of the multiplication of frictional surfaces is illustrated by the diagram Fig. 1, Plate 105, where instead of two series of discs there are shown two series of short flat plates, arranged like the discs alternately with each other. The one series A A are severally tied to the fixed pillar C, and each one of the other series B B has its sides in frictional contact with two of the first series. The applied pressure for frictionally coupling the two series is furnished by the weight D. Upon withdrawing any one of the series B in the direction shown by the arrow, a certain degree of resistance will occur, in consequence of the friction upon its two sides due to the pressure of the weight D. Upon withdrawing two of the series B together, twice as much resistance occurs; and if the whole series B B are simultaneously withdrawn, the resistance is further increased in proportion to the whole number in that series. The double series A B represented in the diagram having eight pairs of rubbing surfaces repeats eight times over the friction due to the weight D acting direct upon one pair of surfaces; and in this case therefore eight is a constant multiplier for the friction due to any given pressure at D. Hence, as the number of the plates or discs may be indefinitely increased, an indefinite increase or extension of frictional area may be obtained, without any reduction of the pressure per square inch upon the rubbing surfaces; in consequence of which the remarkable result is obtained of an indefinite increase in the total amount of friction with the same load.

It may be remarked as an illustration that this principle of the repetition of frictional surfaces is the basis of the structure of ordinary hempen ropes. In that case contiguous fibres present their surfaces to each other in frictional contact, and the frictional adhesion between them is due to the initial pressure given by the original twist in the strands, and to the resultant pressure arising from the oblique direction of the strain upon the fibres under a load; and a rope of an inch diameter is stronger than a half-inch rope because of the greater number of fibres in frictional union which it contains. The "coupling" pressure upon the fibres may be wholly removed by completely untwisting the strands of the rope; and the strength of the rope will then have disappeared, simultaneously with the loss of the frictional union of its fibres.

In Fig. 2, Plate 105, is represented a form of experimental friction break or coupling, composed of two series of circular friction discs A A and B B, the relative motion of the rubbing surfaces being circular, instead of in a straight line as in Fig. 1. The shaft discs A are made an easy fit upon the square shaft C, so that they may slide to or from each other upon the shaft into more or less intimate contact with the intermediate discs B; and the latter, when no coupling pressure is applied, are capable of turning freely upon the circular bosses of the shaft discs A. The coupling pressure is applied or withdrawn by means of the cranked lever D, the short forked arm of the lever compressing the discs longitudinally upon the shaft against the fixed pin E. So long as no compression is applied, the shaft C can rotate freely, carrying with it the discs A, which do not then transmit any driving force to the discs B; but upon compressing the discs into frictional contact with each other, the rotary motion of the shaft will be transmitted by the discs A to the intermediate discs B. The rotation of the shaft being maintained, and the discs B being held from turning by a cord F wound round the circumference of each, the tension upon each cord measures the friction between each two pairs of the circular rubbing surfaces; and the strain upon all the cords taken together is the total force which the whole series of intermediate discs B is then absorbing by break action upon the shaft discs A. The collective strain upon all the cords represents also the tangential force which under the same pressure the discs B will transmit at their circumference when employed as a coupling, together with the difference between the friction of motion and the friction of repose; this strain is indicated by the spring balance H, upon which all the cords pull by the intervention of the crossbar G. The ratio of the strain on the spring balance H to the coupling pressure applied by the lever D is constant for all pressures; that is, in the same coupling and break, or in one containing the same number of friction discs, which have the same pitch line or centre of friction, and are made of similar materials with their rubbing surfaces in the same condition. To illustrate this uniformity of action, the coupling pressure at D may be applied gently and increased by imperceptible gradations to any required extent, and in like manner gradually withdrawn again; and the tangential force indicated by the spring balance H will simultaneously rise and fall with the same steady regularity. The coupling pressure may also be applied and withdrawn very suddenly, or even with a jerk, and proportionate extremes of force will then be indicated with the same abruptness by the spring balance H; and this will be the case, whether the fluctuations of the applied pressure are faint, arising from very minute but sudden variations like rapid pulsations, or whether the variations are excessive as well as rapid. This sensitiveness of the friction coupling is due to the parallelism of its rubbing surfaces, since the frictional action between parallel plane surfaces necessarily fluctuates in true and instant correspondence with every variation of the applied pressure.

The power of the coupling and break, which might be increased if necessary so as to exceed the ultimate strength of the shaft without any sacrifice of sensitiveness, is due to the principle of repeating the frictional surfaces, whereby the total area of frictional contact can be increased indefinitely without diffusing or diminishing the initial pressure between the frictional surfaces; that is, every disc repeats without diminution the frictional effect produced by the applied pressure upon the first pair of surfaces. The arrangement of the double series of alternate discs possesses peculiar advantages in the varieties of adaptation of which it is susceptible, enabling it to be used under widely different conditions. Where the space available for a friction coupling or break is limited in a radial direction, so that the discs are required to be small in diameter, the necessary amount of friction is obtained by extending the coupling lengthwise along the shaft, employing an increased number of the discs to compensate for their small diameter. On the other hand, where the space is limited longitudinally upon the shaft, involving the use of fewer discs, their diameter can be increased to give the necessary amount of frictional surface.

The materials and structure of the discs may be very various. For the severest strains both series of discs are made of iron, one series being faced with wood segments placed endways of the grain. A coupling capable of very high duty, and one very compact in form, is obtained by employing thin sheet steel for the material of both series of discs, and facing one series with leather faces on both sides, the leather being attached by fine copper wire passed through small holes in the steel discs. For break purposes iron and wood discs are employed, and the wood discs are thoroughly saturated with linseed oil and the iron discs made smooth; the wear of the discs then becomes imperceptible. In consequence of the large amount of rubbing surface obtained, the lowest coefficient of friction suffices, and the break may therefore be always lubricated if desired, and is still sufficiently powerful. The pitch line or centre of friction of the discs is the circle dividing their working faces into two equal annular areas. By enlarging the central opening in the intermediate discs, so as to make their working face a narrow annular ring, the pitch line is thrown further outwards from the shaft, and the power of the coupling is thereby increased by increasing the leverage at which it acts; but for break purposes this reduction of the actual area is not always desirable, as it reduces the amount of wearing surface, though increasing the efficiency of the break.

For a coupling required to transmit motion and to cease doing so instantly at definite points in a revolution with exact precision, the intermediate discs are sprung apart by means of small springs placed near their edges, and the shaft discs are sprung apart by small spiral springs in their bosses, as shown in Fig. 2. This plan of springing the discs apart when the pressure is withdrawn renders the coupling applicable to vertical or inclined shafts, or to a shaft having other motions than simply round its own axis. By employing springs of graduated strength between the discs, a coupling or break may be arranged for obtaining a gradually increasing frictional action, by making only one pair of faces come into action first; and during the time that this one pair only is in contact the frictional action between them can be gradually augmented by a gently increasing pressure, until the springs separating the next pair of discs are sufficiently compressed to bring these also into action, and so on until any required number of discs are in action. When all the discs have thus been brought into action the frictional resistance of a break constructed upon this plan will still continue to increase under a further increase of pressure, until all relative motion between the two series of discs has ceased. This arrangement for bringing the discs successively into action will give a graduated effect uniformly increasing by delicate and scarcely perceptible grades up to the full power of the break; and it might be advantageously applied for such purposes as arresting rapid rotation in centrifugal drying machines.

The practical applications described in the present paper of this friction coupling and break are those only which have proved economical and preferable to other frictional appliances; but many other applications are now in progress. For the purpose of hoisting, nearly four hundred crabs, cranes, and hoists, constructed upon this principle, have now been put to work; and the results of their use during five years have proved quite satisfactory. A 5 ton crab on this construction at the Bardon Granite Quarries, Leicester, is now working as well as when first used about five years ago; and during that period it has had nearly constant work in lifting empty trucks.

As friction couplings upon fixed driving shafts a considerable number of these couplings are at work, applied to small shafts of less than 3 inches diameter; and sufficient advantage has been found after nearly three years' trial to lead to the further adoption of the plan for much larger shafts, to which the coupling is now being applied accordingly.

In Figs. 3 to 5, Plate 106, is shown a portion of a 6 ton Hoisting Crab. Fig. 3 is a longitudinal section, and Figs. 4 and 5 are transverse sections showing separately one of the wood discs and one of the iron discs. The shaft discs A, made of wrought iron, are here five in number, with a square hole in the centre of each, fitting upon the square portion C of the shaft, Fig. 5. The four intermediate discs B are of elm wood, and engage with the external drum D by the slots in their edges, into which fit the longitudinal ribs on the inner surface of the drum, Fig. 4. The drum D forms a portion of the pinion casting E, which when uncoupled turns freely upon the shaft; and for the purpose of hoisting it is coupled with the shaft by the frictional action of the discs A B in the same manner as in the preceding examples. The coupling pressure is applied by the handwheel F, the boss of which is screwed to traverse upon the screwed part of the shaft; and by this means the discs are compressed together against the collar G, upon which the pinion turns when uncoupled. The shaft carries at its ends the usual winch handles, and is also provided with the ordinary ratchet-wheel to prevent it turning backwards when the winch handles are released. For lowering the load it is only necessary to turn the handwheel F backwards, unscrewing it slightly from its pressure upon the discs, until the load makes the pinion E run backwards; and the speed of lowering is controlled with great exactness or the descent of the load can be instantly arrested without exertion by again screwing the handwheel forwards upon the break. The advantages obtained in this case are despatch and safety; the winch handles never turn backwards in lowering, and the load is kept completely under control with the greatest ease.

In Figs. 6 and 7, Plate 107, is shown a Sack Hoist, as used without tackle blocks; and with the blocks it forms a convenient hoist for weights up to half a ton. Fig. 6 is an end elevation, and Fig. 7 a longitudinal section to a larger scale. The winding barrel D is loose upon the shaft, and is recessed at one end to form the break drum. The coupling and break is exactly similar to the one last described, the five iron shaft-discs fitting upon the square part of the shaft C, and the intermediate wood discs engaging with the ribs inside the drum D. The rope-wheel F is screwed to traverse upon a screwed portion of the shaft. A ratchet-wheel G fixed upon the shaft prevents it from turning backwards, and also forms a collar or abutment to receive the coupling pressure applied by the screwed boss of the rope-wheel. An endless rope passes over the rope-wheel, and on pulling the rope in the direction for hoisting, the rope-wheel advances upon the screw and compresses the friction discs, until the friction between them is sufficient to couple the winding barrel D to the shaft C. On continuing the hoisting motion the load is then raised, and is held suspended at any point by the ratchet-wheel G. For lowering the load it is only necessary to pull the rope in the opposite direction, and as the shaft cannot turn backwards on account of the ratchet-wheel, the rope-wheel is thereby withdrawn, relieving the friction discs from pressure; and the winding barrel being thus uncoupled from the shaft runs backwards on it with the load. The speed of lowering is under perfect control by holding the endless rope with one hand on each side, and applying the break as required to check the descent of the load, by pulling the rope slightly in the direction of hoisting, so as to screw the rope-wheel up against the friction discs. This arrangement of hoist has the advantage that both the hoisting and the lowering are done at pleasure by means of the single endless rope, which affords perfect control over the load at all times.

In Figs. 8 and 9, Plates 108 and 109, are shown portions of one of Messrs. Harfield's Ships' Windlasses for a 2 inch chain-cable, the frictional apparatus being employed as a "connector" or coupling, and also as a break. This application has been approved by the Admiralty, and the windlass has been introduced for use in the navy. Fig. 8 is a sectional plan and Fig. 9 a transverse section of the windlass, taken through the break drum. The cable-holder or chain-wheel C is cast in one piece with the break drum D; and when the friction discs are uncoupled, the chain-wheel can turn freely on the horizontal shaft E, which is supported in the cast-iron framework F F of the windlass. The shaft E is rotated by the pair of nipping wheels H keyed upon it, one of which only is shown in the drawing, each wheel being fitted with a nipping lever G; the pair of nipping levers receive an alternate up and down motion from a reciprocating sway beam, at the opposite ends of which the two levers G are attached, the beam being worked up and down by manual labour. In the downward movement of the nipping lever it slips down freely over the rim of the wheel H until it jams itself; and then in the upward movement it bites or nips the wheel and turns it forwards through a portion of a revolution: in this way by the alternate action of the pair of nipping levers the shaft E is rotated with a continuous motion in the direction of the arrow in Fig. 9.

The boss of the nipping wheel H projects inwards within the break drum D, Fig. 8, to a sufficient distance to carry the required number of friction discs; and its exterior is shaped with three solid keys J J, Fig. 9, which engage in corresponding slots in the iron shaft-discs A. There are six of the shaft-discs, which are made of wrought iron galvanised for preventing corrosion. The seven intermediate discs B B are made of teak wood, and are of square outline with the corners bevilled off, engaging with the drum D by their angles, as shown in Fig. 9. The coupling pressure for compressing the friction discs together is applied by means of the screw N turning loose on the shaft E and working in the nut M, to which the back plate K at the further end of the series of friction discs is connected by the three longitudinal bolts L passing through holes in the boss of the nipping wheel H; by turning the screw forwards the back plate K is tightened up towards the nipping wheel H, compressing the discs with the required pressure. The screw N is made with a capstan head, having recesses O round its circumference to receive a hand lever for turning it, when a heavy pressure is required upon the friction discs for coupling the chain-wheel C solidly to the nipping wheel H. For light pressures or for break action the screw is turned by the small handles P fixed round its circumference; and one quarter turn of the screw is sufficient to stop altogether the running out of the cable or to release it entirely.

One end only of the windlass is shown in the plan, Fig. 8, and the opposite end of the shaft E carries an exactly similar chain-wheel C and nipping wheel H; so that the continuous rotary motion given to the shaft E by the pair of nipping wheels H may be transmitted to either one of the chain-wheels C by applying the coupling pressure to the set of friction discs with which each chain-wheel is provided. As a connector this application of the friction discs offers the advantage of connecting the chain-wheel with the shaft of the windlass at any point in a revolution, without letting go of the cable or taking in any more of it; and as a break its power and compact form have proved very advantageous. A windlass of the size shown in Figs. 8 and 9 is suitable for a ship of 1800 tons register, the iron shaft-discs being 23 inches diameter and ¼ inch thick, and the intermediate teak discs 23 inches square and ¾ inch thick.

In an experiment with one of these windlasses of a smaller size, containing six pairs of the friction discs, upon which the coupling pressure was applied by a lever 3½ feet long with the force of two men, the friction break served to hold and control a direct pull upon the cable of 34 tons, without injury to the friction discs. In this case the iron discs were 14¼ inches diameter and $\frac{3}{16}$ inch thick, as shown in Fig. 10, and the wood discs were ¾ inch thick with a centre hole 11 inches diameter, as shown in Fig. 11.

In Fig. 12, Plate 110, is shown a simple form of Shaft Coupling, employed to drive shaking or tumbling barrels at Messrs. Nettlefold's screw works, Birmingham. Fig. 12 is a longitudinal section, and Figs. 13 and 14 are transverse sections showing the iron and wood discs separately. The five iron discs A engage with solid keys on the long boss of the spur wheel E, within which the driving shaft C turns freely when no coupling pressure is applied to the discs. The drum D containing the six intermediate wood discs B slides on feathers on the shaft C, and the groove G on the outer end of the drum receives the forked end of a lever by which the coupling pressure is applied, compressing the discs against the fixed collar F on the shaft, and thereby coupling the spur wheel E to the shaft C. To prevent wear, the forked end of the lever is faced with segmental pieces of hardened steel; and the loss of power by end pressure upon the shaft is not found to be any serious amount. The advantage realised by this arrangement of frictional shaft coupling is the prevention of breakage to gearing and straps, which was previously of very frequent occurrence.

In Figs. 15 and 16, Plate 111, is shown a Safety Clutch, intended simply for preventing breakage by overstrains; it was constructed for driving agricultural machinery by the power of oxen. Fig. 15 is a longitudinal section, and Fig. 16 an end elevation and transverse section. The clutch forms a frictional connection between the two shafts C and E placed in line with each other, the shaft C carrying the four iron discs A, which slide on keys upon it, while the other shaft E carries the drum D securely keyed to it. A cover plate, through which the shaft C passes freely, is secured to the drum D by the six bolts G G passing through near its outer edge; and these bolts form the ribs or projections inside the drum for engaging with the five intermediate wood discs B. The coupling pressure is applied by the four set-screws H H, which are adjusted by hand to the required pressure. By this means the power which the clutch will transmit without slipping can be adjusted with nicety, according to the work to be done or the strength of the machines to be driven; and any sudden increase of resistance or of driving power, beyond the limit to which the clutch is adjusted, will cause the friction discs to slip upon one another, whereby all liability of injury or breakage is prevented.

In Figs. 17 and 18, Plate 112, is shown a Self-Engaging Friction Coupling, applied to shafting at Messrs. Whitbread's brewery in London. The driving shaft C carries the four iron discs A, as before, and the drum D containing the five intermediate discs B of elm wood is keyed on the driven shaft E. The coupling pressure is applied by the spiral springs I I, inserted between the inner end of the drum and an iron disc or cover plate K bearing against the first of the wood discs B. The plate K is connected by the bolts H with the exterior sliding collar G, which is grooved to receive the steel ring L carried by the forked end of the hand lever M; so that by means of this lever the coupling pressure can be taken off the friction discs at any time; and by locking the lever in this position with the pressure withdrawn, the coupling ceases to transmit the power from the driving shaft C, and the shaft E with the drum D accordingly remains at rest. On releasing the lever M, the coupling immediately throws itself into gear again, with a self-engaging action, by the springs I pressing the series of discs into frictional contact; and the two shafts are then coupled and revolve together, without any loss of power by end pressure.

In Fig. 19, Plate 113, is represented an application of the friction coupling as a Lathe Coupling, as applied by Messrs. Tangye of Birmingham to a three-spindle lathe. The drawing is a transverse vertical section through the lathe-bed and saddle. The friction coupling is applied to the back-traverse motion of the lathe, in place of the ordinary cone clutch so often employed in similar situations, which however is found not to transmit sufficient power nor in so convenient a manner for lathes of this description, where there are three cutting tools acting simultaneously. The back shaft K carries as usual a travelling wormwheel geared to the tangent wheel M, which is made with a projecting hollow boss L that contains the intermediate friction discs of elm wood. The iron shaft discs are carried on the hollow shaft N N, on which is also fixed the spur pinion O gearing with the ordinary traverse rack R by means of the spur wheels P P. Within the hollow shaft N is a rod T T, having at one end a large collar or plate to pull inwards against the friction discs; and on the other end of the rod T is a small cross lever S with screwed boss, by means of which the coupling pressure is applied upon the friction discs, when it is required to couple the tangent wheel M to the hollow shaft N.

In Figs. 20 and 21, Plate 114, is shown a form of Safety Pinion, intended to prevent the shaft to which it is applied from transmitting or receiving any excess of force beyond a fixed limit. The iron shaft discs A A, shown in section in Fig. 20, are here bevilled in one direction, and the intermediate discs B B, which in this case are also of metal, are bevilled in the opposite direction. This sectional form gives great compactness, allowing nearly double the number of discs of any given strength to be placed within the same longitudinal space upon the shaft C. The discs are tightened up with the required amount of coupling pressure by means of the nut E. The intermediate discs B are made larger in diameter than the shaft discs A, to a sufficient extent to allow of the pinion teeth F F being formed in the projecting rims of the intermediate discs, as shown in Fig. 21.

In Figs. 22 and 23, Plate 115, is shown a Sack Hoist, intended for small weights up to 5 cwts., and possessing the valuable property of being self-sustaining, so that the load can in no case run down of itself, but requires to be lowered continuously by the hand rope. The rope-wheel F and the winding barrel D are both loose upon the main shaft C, between the small fixed collar E and the large disc H cottered on the shaft; a ratchet-wheel G, Fig. 23, keyed on the shaft between the collar E and the rope-wheel, prevents the shaft from turning backwards. The boss of the rope-wheel F has its outer face made plain and smooth for frictional contact with the adjacent side of the ratchet-wheel G; and the flange K at the other end of the winding barrel D is in like manner faced to rub against the disc H. The side of the rope-wheel boss F that is adjacent to the winding barrel is formed with a spiral inclined face I or single convolution of a screw, which engages with a similar spiral incline J formed upon the end of the winding barrel D. The diameter of the other side of the rope-wheel boss which rubs against the ratchet-wheel G is made rather greater than the diameter of the screw inclines I and J; and the pair of rubbing faces formed by the flange K and the disc H are made as large as convenient, for the purpose of gaining break power in lowering.

The action of this construction of hoist is as follows. On turning the rope-wheel forwards, in the direction for raising the load, the inclined surface of the spiral between the rope-wheel and winding barrel tends to separate them endways, and thus produces an end pressure, which tightens together the external plain rubbing surfaces with a pressure proportionate to the load sustained by the winding barrel. The rope-wheel and winding barrel are thus jammed between the fixed collars E and H on the shaft, and the several parts of the hoist are thus firmly coupled together, so that the continued forward rotation of the rope-wheel F carries with it both the winding barrel D and the shaft C, thereby raising the load and turning the ratchet-wheel G forwards. For lowering the load, the rope-wheel being turned backwards by hand withdraws one incline from the other in the spiral clutch, and thereby relieves the friction surfaces from the end pressure, so that the winding barrel is released and the load can descend; but the descent of the load can only take place so long as this withdrawal of the inclines is continued by the rope-wheel continuing to be turned backwards by hand, allowing the winding barrel to follow. The moment the rope-wheel is stopped, the inclines become tightened again upon each other by the load acting on the winding barrel; the rope-wheel and winding barrel are thus again jammed endways between the friction surfaces of the ratchet-wheel G and disc H, which being held by the ratchet from turning backwards prevent the load from running down further. This arrangement accordingly provides the means of lowering as well as raising the load continuously and steadily and with perfect safety, avoiding the risk of injurious jerks on the chain; while at the same time the load is securely held suspended at any point at which the rope-wheel may be stopped.

In the construction of this hoist, the diameter and angle of the spiral inclines, and the diameter of the frictional surface presented by the ratchet-wheel, are so proportioned as not only to make the load self-sustaining at any point at which the hoisting force ceases, but also to render the lowering motion self-arresting; so that the descent of the load ceases as soon as the backward turning of the rope-wheel by hand is discontinued, and the winding barrel in running backwards under the influence of the load is not able to drive the rope-wheel before it by means of the inclines, however great may be the load suspended from the winding barrel. In the sack hoist shown in Fig. 22 this result is attained by making the diameter of the frictional surface of the ratchet-wheel a little greater than the diameter of the spiral inclines, the friction surfaces in this case being iron upon iron, and the pitch of the spiral being $\frac{1}{2}$ inch in a diameter of 4 inches, giving an angle of about 1 in 24 for the inclines. This very fine pitch is intended for light weights only, and for heavier loads a coarser pitch would be employed with a proportionately larger diameter for the friction surface of the ratchet-wheel. When the proportions of these parts have been suitably adjusted for sustaining any given load, the self-sustaining and self-arresting property of the hoist is not affected by any increase or diminution in the load, because any change in the load is attended with a proportionate change in the amount of end pressure produced by the inclines and in the consequent frictional resistance offered by the rubbing surface of the ratchet-wheel. Under any load whatever therefore the frictional resistance or adhesion between the rubbing surfaces of the ratchet-wheel and the rope-wheel boss, arising from the oblique action of the inclines, is always greater than the direct rotary driving force of the winding barrel upon the rope-wheel through the inclined faces of the spiral clutch. With the proportions above mentioned, the sustaining friction is so little in excess of the load that only a slight amount of force is sufficient to turn the rope-wheel backwards for lowering the load; and the rope-wheel being made heavy, to act as a flywheel, a tolerably vigorous pull upon the rope causes the wheel to make a number of revolutions backwards, allowing the winding barrel to follow and lower the load with proportionate rapidity; but as the frictional resistance slightly preponderates, the lowering takes place with perfect safety, and the load gradually ceases to descend as the rope-wheel loses its momentum. The lowering of the load therefore continues only so long as the backward motion of the rope-wheel is continued by hand, and the descending load comes to rest at any moment that the rope-wheel ceases to be turned backwards. The one endless rope thus affords the means of both raising and lowering weights continuously and steadily, by simply working the rope-wheel by hand in opposite directions; and at the same time all possibility of accident from the load running down of itself is avoided.

The frictional faces by which the load on the hoist is sustained are iron upon iron, where lubrication can be depended upon; but in other cases one wood face is introduced. This construction of hoist is also capable of very advantageous combination with the friction disc coupling and break previously described, where a large amount of break power is required; but for a variety of purposes the use of the spiral inclines renders the addition of the friction discs unnecessary.

In Figs. 24 and 25, Plate 116, is shown a Bracket-Winch or Side-Winch, constructed upon the same self-sustaining principle as the sack hoist last described, the lowering being done continuously by turning the handle of the winch backwards, so that the load is lowered slowly and cannot run down of itself. One of the spiral inclines or screw faces is here formed upon a collar I, fixed upon the shaft C of the winch, which is turned by the handle F; and the other corresponding incline J is formed upon the end of the winding barrel D, which is loose upon the shaft. The flange K at the other end of the winding barrel is faced to rub against the ratchet-wheel G, which runs loose upon the boss of the flanged collar E cottered on the shaft C, the ratchet-wheel being situated between the flange E of the collar and the flange K of the winding barrel. The shaft C and winding barrel D are carried in a trough-shaped casting or bracket L L; and a recess in the framing of the bracket contains the paul H, Fig. 24, of the ratchet-wheel G. The action of this winch is exactly similar to that of the hoist last described, the spiral inclines having the effect of jamming the winding barrel endways against the ratchet-wheel and the fixed collar E; and the frictional surfaces sustaining the load in this case are the two sides of the ratchet-wheel G, which are in contact respectively with the flange of the collar E and the flange K of the winding barrel.

In Figs. 26 and 28, Plate 117, is shown a portion of a self-sustaining Hoisting Crab, in which the application of the spiral inclines as already described is combined with the friction discs of the couplings and breaks previously described, the lowering of the load being performed slowly by continuously turning the handles of the crab backwards, in the same manner as last explained. The pinion D runs loose upon the shaft C of the crab, and is cast with a long boss of square exterior, which carries the two iron shaft-discs A A. The ratchet-wheel E, also turning loose upon the shaft C against a fixed collar, is cast in one piece with the break drum F, shown in section in Fig. 28, which contains the three intermediate wood discs B B. The collar G fixed upon the shaft has its end next to the pinion D formed into a spiral incline or screw face, which engages with the corresponding incline H formed upon the pinion D. The shaft C is rotated by the usual winch handles, and on turning it in the direction for hoisting, the inclines G and H ascending each other slightly produce a longitudinal pressure upon the friction discs A and B, thereby coupling the pinion D to the ratchet-wheel E, and both of them to the shaft C; the load is then raised by continuing to turn the shaft forwards, and is sustained at any point by the paul of the ratchet-wheel E. The lowering is done, as before, by turning the winch handles backwards, thereby relieving the friction discs from the pressure of the inclines; and the lowering takes place only so long as the winch handles continue to be turned backwards, and ceases as soon as they stop. The friction discs employed in this case serve to increase the area of the frictional rubbing surfaces and thereby diminish the wear upon them; they also afford the required amount of frictional connection with much less end thrust from the inclines, so that the longitudinal strain upon the shaft and collars is thereby reduced. The angle of the inclines may therefore be increased, and in the present instance it is made about 1 in 12, or a pitch of $\frac{5}{8}$ inch in a diameter of $2\frac{1}{2}$ inches.

In Figs. 27 and 28, Plate 117, is shown another arrangement of Hoisting Crab, in which the combination of the spiral inclines with the friction discs is applied in a different manner, and with a different result, allowing the load to be lowered quickly. The pinion P as before is loose upon the crab shaft I and its square boss carries the two iron shaft-discs A, the three intermediate wood discs B being contained in the drum O cast in one piece with the ratchet-wheel N, which is also loose upon the shaft I. The fixed collar L however, on which is formed one of the spiral inclines, engages with the other incline M formed in the present arrangement upon the ratchet-wheel N, instead of upon the pinion P as in the preceding case. In hoisting, the effect of the inclines is the same as previously described, jamming the ratchet-wheel N and pinion P against the fixed plain collar K upon the shaft, and putting an end pressure upon the friction discs A and B, sufficient to couple the pinion to the ratchet-wheel, and both of them to the crab shaft I. But in lowering, the result of the difference in the present arrangement is that it is only necessary to turn the winch handles very slightly backwards in order to relieve the friction discs entirely from the coupling pressure; the pinion P is thereby liberated altogether from the friction by which alone it was held, and the load is then free to run down of itself. This arises from the circumstance that, as the incline M is here formed upon the ratchet-wheel N, which is held by the paul from turning backwards, it is prevented from following the other incline L when the latter is withdrawn by turning the crab shaft backwards; a slight backward turn of the winch handles is consequently sufficient to remove the end thrust or jamming action of the inclines, thereby annihilating altogether the frictional resistance by which the load was sustained. The descent of the load can be checked or stopped altogether at any moment with break action by turning the winch handles forwards again in the direction for hoisting, so as to restore the coupling pressure upon the friction discs by the action of the inclines; and the winch handles thus form a ready means of applying or withdrawing the pressure upon the friction break. The load is therefore under perfect control at all times without danger to the men working the crab; and great despatch is obtained by making the winch handles serve the double purpose of hoisting the load and applying the break in its descent.

The preceding arrangement of crab, shown in Fig. 26, gives a very safe lowering motion, but only as quick a one as can be conveniently imparted by the continued backward rotation of the winch handles. The present arrangement, shown in Fig. 27, allows the load to run down freely of itself, but the rapidity of its descent is checked and controlled at pleasure by the application of the friction break by means of the winch handles. The absolute safety attending the self-sustaining slow-lowering crab is therefore wanting in the present quick-lowering crab; or rather the safety is here dependent upon the care exercised in applying the break.

The rather slow but unquestionably safe lowering motion obtained by the arrangement shown in Figs. 22 to 26 is considered by the writer to be of especial value for jib cranes and other hoisting apparatus, where it is necessary to guard against the framework or foundations being exposed to any injury from suddenly checking by break action a load descending at an excessive speed. This arrangement would also be useful and safe as a means of varying the angle of inclination given to the jib of derrick cranes, and retaining the jib securely in any desired position without risk of slipping. In like manner it could be applied to wind in or let out the guys or stays of sheer legs and other hoists of similar structure; and generally for any purpose where a very safe backward motion is required for any pinion or drum upon its shaft, this hold-fast or self-sustaining arrangement would be valuable. The combination of the spiral inclines with the friction discs, in the manner shown in Fig. 26, furnishes a powerful and continuously self-acting break; that is, as fast as the coupling pressure is withdrawn, permitting the load to descend, it is continuously restored again by the load itself, so that the load is thus entirely incapable of running away; and as the power of the discs for break action may be increased to almost any degree, any load, however great, may be lowered in this manner with absolute safety.

Mr. WESTON exhibited a number of working models and specimens of the various applications of the friction coupling and break, and showed the raising and lowering of weights by the two constructions of sack hoist described in the paper, the first plan allowing the load to run down freely when released by the handwheel rope, which also served as a break to check the descent at any moment, while the second plan required the handwheel to be continuously turned backwards during the whole time of lowering.

Mr. E. A. **Cowper** thought the new arrangement of friction break or clutch was very good and would be available for many purposes. One of the most valuable applications of the plan appeared to him to be the frictional spur gearing shown in Figs. 20 and 21, where the safety pinion was composed of a series of pinions or toothed discs loose upon the shaft, alternating with plain discs fitted to the shaft, and by compressing the whole together endways each pinion was pinched equally between the shaft discs, so that each would do exactly the same amount of work, and the driving power transmitted by the whole pinion would be equally distributed across the entire breadth of the teeth of the spur wheel geared with the pinion. The two different modes of lowering the load in the two frictional crabs were also very good, the same principle of the inclined plane being employed in each case, either for relieving at once the whole end pressure on the friction discs, or for easing it off gradually by turning the winch handle backwards continuously. The latter plan had the advantage of being very safe and avoiding jerks, as the load could not run down of itself; and the former gave great facility for lowering very quickly in cases where there was not any danger from rapid lowering, as in the instance of lowering empty barrows &c. in connection with builders' scaffoldings. The thickness of the alternate iron and wood discs employed in the various couplings and breaks was certainly very small, the iron discs being only $\frac{1}{4}$ inch thick and the wood $\frac{3}{4}$ inch thick; and he enquired in reference to the wear and tear upon them, whether the wood discs being so thin had been found to give way in any case at the circumference under the strain to which they were subjected.

Mr. **Weston** replied that in the early form of the windlass break the plan of holding the wood discs by means of notches fitting upon projecting ribs in the interior of the drum containing the discs, as shown in Fig. 4, was found insufficient, and the wood was liable to break away from the projections when subjected to a heavy strain;

and the square form for the outside of the wood discs was then resorted to, as shown in Fig. 11, with the corners of the square discs bevilled off, which was found to get over the difficulty completely, and had never failed. For cranes and crabs however the first form of discs answered well.

Mr. E. A. **Cowper** observed that the use of an iron disc interposed between two iron discs lined with wood, for the purpose of forming a friction clutch, had been adopted by Mr. Ramsbottom in the reversing rolling mill at Crewe, for connecting the engine shaft to the rolls (see Proceedings Inst. M.E. 1866 page 116); in that case however the two wood surfaces were nipped between the iron discs by bolts all round the circumference, each tightened up separately, so that the pressure could only be adjusted approximately in the first instance, and there was no means of altering it quickly for variations in the amount of driving power to be transmitted. The employment of a number of friction discs, as in the new arrangements now described, had the advantage that much less pressure upon the discs was required for transmitting the same amount of power; and by employing a sufficient number of discs in the coupling it might even be possible to throw a heavy mill in and out of gear, or to reverse it, by means of a friction coupling, with the power of only one man acting on a hand lever. He thought the several applications which had been described only required to be more known in order to be more generally used. One point that occurred to him was, that in the use of the incline or spiral clutch for putting the end pressure upon the frictional surfaces in the hoists described in the paper, if the inclination of the spiral were supposed to be 12 to 1, the end pressure produced by it would be twelve times as great as the load on the chain barrel, and consequently there would be a shearing strain of that amount upon the pin holding the fixed collar on the shaft.

Mr. **Weston** replied that it was so, but as the loads lifted by that construction of hoist were not great, the end pressure upon the collar was not material; and it could be reduced to any required extent by the introduction of friction discs in combination with the inclines, as shown in the crabs.

The CHAIRMAN enquired whether any data could be furnished in reference to the amount of power that could be safely transmitted with a given extent of frictional surface, so as to allow of some idea being formed as to the number and size of discs required for a clutch to drive a rolling mill for instance; as the applications to shafting described in the paper did not appear to extend to the case of very large shafts.

Mr. WESTON replied that the nearest approach to the case of a clutch for driving rolls in ironworks was the windlass break for ships, shown in Figs. 8 and 9, in which it was found that six pairs of the discs of a smaller size than there represented were amply sufficient to hold against a pull of 34 tons on a ship's cable. In that case the iron discs were 14¼ inches diameter, and the central hole in the wood discs was 11 inches diameter, the material of the discs being wrought iron and teak alternately; the end pressure upon the discs for sustaining the strain of 34 tons was applied by means of two men acting on the break screw (N, Fig. 8) by a hand lever 3 feet long.

Mr. W. F. BATHO said he had introduced the friction coupling for driving the shafting and machinery at Messrs. Nettlefold's screw works which had been referred to in the paper, and it had been found of very great advantage there, and was now used in all cases where previously the ordinary clutches had been employed. It was a very ingenious application of a simple principle, which he thought was capable of very extensive adaptations. With regard to the wear of the wood discs, he had found this to be very slight, scarcely indeed amounting to anything appreciable; and the only way in which he could imagine that the coupling could be injured by a strain put upon it would be by the end pressure on the discs being very suddenly applied under a heavy strain, in which case the strain would be thrown upon the iron discs more in the manner of a blow, and might possibly occasion wear of the keys connecting the iron discs to the shaft, and so cause the discs to get loose and break the keys. He had not had any experience however of strains sufficiently heavy to produce such a result in any of the couplings that he had adopted.

Mr. WESTON remarked that in the couplings intended for heavy strains the size of the main shaft gave the three keys holding the iron discs sufficient leverage to withstand any concussive action arising from throwing the strain suddenly upon the coupling. This was satisfactorily proved by the results of working of the windlass break for ships' cables, which had been approved and adopted by the Admiralty; and the plan had also been used by Messrs. Harfield of London for driving ships' capstans by steam power. The durability of the wood discs in the couplings and breaks was sufficiently established by Mr. Penn's experiments on wood bearings, which had satisfactorily proved that under a pressure of even 1200 lbs. per square inch on lignum vitæ running on iron no perceptible wear took place during long continued working (see Proceedings Inst. M. E. 1856 page 27). In the present case the wood used for the discs in the ships' windlass was teak, which of course would not be so durable as a harder wood; but at the same time the pressure per square inch upon the friction discs was far less than in the above experiments. Elm was employed for the discs of the cranes and smaller hoists.

Mr. C. W. Siemens observed that in the experiments on wood bearings the rubbing surfaces were immersed in water, and he enquired whether the wood discs in the friction break were lubricated with oil or water.

Mr. Weston replied that the wood discs were saturated with linseed oil before being put in their places, and when so treated he had not found they required any further attention or lubrication subsequently under any pressure that they were subjected to.

Mr. E. H. Carbutt mentioned that a useful application of the wood friction discs on a small scale had been made to the bearings of looking-glasses, so as to hold the glass firmly in any position into which it might be turned; he had seen one of these small bearings very severely tested by being put in a lathe and run continuously for a week under pressure without lubrication, and no perceptible wear of the wood had been produced.

The Chairman observed that the double amount of friction arising from the two sides of a plate or disc being both in frictional contact had hitherto been recognised in general only as a difficulty to be overcome in connection with machinery; as in the case of a steam engine having two slide-valves, one on the back of the other, where the extra friction on the lower slide due to the double surface not infrequently occasioned breakage of its valve rod. This principle however of the friction increasing with the number of surfaces in contact, which had previously been only a source of trouble, had now been taken advantage of in a very ingenious manner in the construction of the friction coupling and break described in the paper. He had had the opportunity of seeing the shaft couplings on this plan at Messrs. Nettlefold's works, and considered that nothing could possibly work better than that arrangement; and he was therefore fully prepared to hear that it had been found entirely satisfactory in continued working, as had now been stated.

He proposed a vote of thanks to Mr. Weston for his paper, which was passed.

The following paper was then read:—

ON THE MOULDING OF TOOTHED WHEELS, AND AN IMPROVED WHEEL-MOULDING MACHINE.

By Mr. GEORGE L. SCOTT, of Manchester.

The apparatus for Moulding Toothed Wheels to be described in the present paper has been designed by the writer to supply the means of obtaining strictly accurate castings by machine moulding, with a portable and self-contained machine of small cost, capable of being readily and quickly applied at any part of a foundry.

The accuracy and perfection of the teeth of wheels are of great practical importance in all cases of gearing, and especially where large amounts of power are transmitted by them; and it is requisite that the transmission of power should be uniform and continuous through the teeth of the wheels, corresponding to the continued frictional contact of two circles rolling upon each other. To maintain this uniform and continuous action in toothed wheels, all the teeth throughout the circumference of the wheel are required to be precise duplicates of one another in form, size, and spacing; and all to be placed in a perfect circle round the centre of the wheel. Should these conditions be imperfectly carried out, the essential continuous contact will be destroyed, and a serious intermittent knocking between the teeth will be caused, leading to the fracture of the wheel, and risking a stoppage of the machinery. Any defective fitting of toothed wheels also involves a waste of driving power from the irregular shocks in transmitting the power; and as a consequence the wheel will not last so long in such a case, owing to the friction causing extra wear of the teeth.

In the earliest method of making toothed wheels, the teeth were chipped out by hand from the solid edge of the wheel, upon which they were set out and shaped to template. Subsequently the teeth were formed on a wood model of the wheel, and moulded from this model according to the plan in general use, involving the necessity of having a separate expensive pattern for each wheel that differs in form and pitch of teeth as well as in diameter. The result has been a vast collection of toothed wheel patterns to meet the requirements of ordinary trade demands; and this stock has become so costly in the expense of construction and of the storage space occupied, that it has led to an objectionable limitation in the range of pitch of wheels, in order to reduce the extent of the stock of patterns. The use of wood patterns for entire wheels involves further the practical objection of liability to distortion, both in the general contour of the wheel and in each tooth, owing to the irregular effects of expansion and contraction in the component parts of the pattern; as well as the unavoidable risk of variation in the forms and dimensions of the several teeth, in consequence of the different finish that each receives. The uncertainty too attending the drawing of an unwieldy pattern from its mould, and the distortion of the pattern that occurs from its lying in damp sand for a considerable time, are additional obstacles to the manufacture of a toothed wheel from the ordinary wood models with the correctness that is desirable.

The only method of overcoming these difficulties is by employing only a small segment as the pattern, and moulding the entire toothed circumference by repetition of this small portion: employing mechanical means for lowering and raising it, and for spacing out the teeth round the circumference of the wheel, so as to obtain the same certainty of accuracy throughout as is shown by a wheel divided and cut in a machine. This process was introduced by Mr. P. R. Jackson, and carried out with the greatest accuracy; and until the advent of his most valuable machine it may be said that no really correct toothed wheels were cast.

The object of the Wheel Moulding Machine forming the subject of the present paper is to extend the application of this process by the use of a portable machine, of small size and cost, that can be easily applied for moulding a toothed wheel in any part of a foundry. Having moulded one wheel, the machine can be fixed at another place for use, or be put away until required again, in the meantime leaving the foundry floor clear and in the usual condition for ordinary work. It will enable any foundry to supply with rapidity and economy of manufacture wheels possessing the absolute accuracy which results from the use of a machine.

The machine is made of two sizes, one for moulding wheels from 12 inches to 5 feet diameter, and a larger size for wheels from 20 inches to 12 feet diameter. The smaller machine is shown in Plates 118, 119, and 120; and one of the machines is exhibited to the meeting. Fig. 1 shows an end elevation of the machine, Fig. 4 a side elevation, and Fig. 5 a plan.

A pedestal A, shown separately in Fig. 2, supports a centre pin B, which has a collar to bear upon the pedestal, and is provided with a projection that fits into a recess in the top of pedestal, whereby it is prevented from turning in its socket. The spindle C is bored to fit on the centre pin B, and is turned to pass up through the rest of the apparatus, which it supports, as shown in section in Fig. 6, Plate 120. Set-screws placed in the spindle C are used to fix it firmly on the centre pin B, and this being secured in the pedestal a continuous vertical centre spindle is thus obtained. Loose collars provided with set-screws and bored to fit the centre pin B are used for the purpose of elevating the apparatus above the pedestal A, in order the more readily to adapt it for moulding different breadths of wheels. One of these collars is shown at V in Fig. 11, and they are of 1, 2, and 3 inches in thickness respectively.

On the spindle C is carried the head D, shown in section in Figs. 6 and 7, and in this head slide the radial arms E E, connected together at their front ends by the transverse piece F, which forms the bed for the vertical sliding ram G. The arms E E are secured to the head D in any required position by four square-headed bolts passing through slots in the arms and through ears cast on the head; these bolts being screwed up bind the arms and head firmly together. The spindle C being firmly secured in the pedestal forms a stationary centre pillar for the machine, on which the head D is free to turn; and on the top of the spindle is keyed the wormwheel H, from which a connection is made to the arms E by the dividing apparatus shown in Figs. 1, 4, and 5. This consists of a worm I gearing into the wheel H, and the change wheels J J J, the uppermost wheel being on the worm shaft and the lowest one keyed on the shaft K, which is carried by brackets on the arm E, and is provided with a loose collar acting as a bearing, so that the shaft may be withdrawn for altering the change wheels when required. The swing frame L carrying the change wheels is sufficient for two intermediate change wheels if required. On the shaft K is fastened a spring handle M, which fits a slot in a disc that is divided to guide the workman in the number of turns to be given to the shaft. The traversing screw O is carried by brackets on the arm E, and passes through the nut N bolted to the head D, so that by turning the screw O by the handwheel at the end the arms are moved in or out, to suit the varying diameters of wheels to be moulded.

On the slide bed F fits the vertical sliding ram G, which is held in by the cover R, shown in section in Fig. 8; and a hand screw S retains the ram in any required position. The bottom of the ram is bored to receive the angle bracket T, which is secured in it by steady pins; and to this is attached the segment pattern U of the wheel teeth to be moulded. The ram is moved up or down by a handwheel Y, having a worm gearing into a wormwheel, on the shaft of which is a pulley Z; from this pulley two chains pass in opposite directions, the one being secured to the bottom of the ram and the other to the top, and kept always tight by means of two lock nuts. An adjustable brass collar W is fitted on the ram, for indicating to the moulder when the ram is sufficiently lowered. An eye-bolt is fixed on the top of the centre pillar C of the machine, for attaching the foundry crane in order to remove the machine.

The process of moulding a wheel with this machine is as follows. A core box for the arms of the wheel is first prepared, and also two radial boards for strickling the form of the top and bottom of the wheel in the sand, which are shaped to the profiles of the face and back of the wheel. The top board P, shown in Fig. 11, has on its lower edge the profile of the back of the wheel; and the bottom board Q has also on its upper edge the counterpart profile of the back of the wheel, and on its lower edge the profile of the face. A pattern is also made of a segment of the toothed rim of the wheel, consisting of two teeth only, which permits of moulding one space at a time.

A secure and steady foundation for the moulding machine is obtained by sinking in the sand of the foundry floor in the desired situation the pedestal of the machine, which is bolted to a cast-iron base-plate about 4 feet square; sand is then rammed solidly upon it, and the pedestal levelled so as to be truly vertical. Another form of pedestal is shown in Fig. 3, which is used for fixing in the sand without a base-plate. The top of the pedestal is placed about 15 inches below the floor level, this distance determining the greatest breadth of wheel that can be moulded. The centre pin B of the machine is then placed in the socket of the pedestal, for the purpose of forming the mould for the bed of the wheel, and also to mould the top box or other arrangement used to cover the mould for casting: the rest of the machine being laid aside for the present.

In Fig. 11 is shown the loose collar V which is placed upon the centre pin B, of such thickness that its upper face is the same depth below the floor level as the breadth of the rim of the wheel to be moulded; so that the back of the wheel is level with the floor, for convenience of fitting the top box on. This lower collar V is fixed by a set-screw, and an upper loose collar X is also fitted on the centre pin B by a set-screw, with its upper face at the same height above the collar V as the breadth of the rim of the wheel; the lower collar thus exactly indicates the level of the bed and face of the wheel, and the upper collar that of the back of the wheel. The hole is then filled up with sand to the level of the upper collar; and the iron trammel carrying the top board P is placed upon the spindle B, and worked round upon the collar X, forming a mould of the back of the wheel, which is then sprinkled with parting sand to form the parting for the top box. An ordinary top box or other sufficient covering is then placed on, and rammed up with sand; and the box is then staked in the ordinary manner, for the purpose of marking its correct position relatively to the bottom part of the wheel, by stakes driven into the sand and fitting by the side of corresponding ears upon the top box. The top box is then lifted off, carrying with it the impression of the back of the wheel; which impression is finished by turning the box over, and strickling it again with the second trammel that carries the bottom board Q. A centre is provided in the top box for this trammel, by means of a loose collar, in which are two bolts that pass through the top box and are fastened across the bars of the box. This loose collar fits the spindle B, and is drawn from it with the top box, thus fixing a strictly accurate centre. By this arrangement the centering collar can be readily fixed upon any ordinary top box, giving strict accuracy in the moulding, without requiring any special boxes for the purpose.

For forming the bed of the mould the top collar X is then removed, and the mould being dug out to the level of the bottom collar V, the sand is strickled with the bottom radial board Q, worked round upon the bottom collar V. This forms the mould for the lower and outer faces of the teeth, and finishes the mould ready to receive the teeth and the cores for the arms; and as both the back and the face of the wheel have been struck from the same trammel and the same centre, perfect accuracy is ensured in the wheel.

The segmental pattern of the teeth U, Figs. 9 and 10, is then fitted truly square and central and secured by screws upon the angle bracket T of the vertical sliding ram G, Fig. 4. The upper portion of the machine is then placed upon the spindle B, the trammel having been removed; and the fixing screws in the spindle are screwed up, to maintain the central axis continuous through the machine. The segmental pattern U is adjusted by the traversing screw O, Fig. 5, to the correct radius of the wheel, measuring from the top of the tooth to the centre of the machine. The ram G is then lowered to the level of the bed of the wheel, and secured at that point by the locking screw S; and the brass collar W is adjusted on the ram and fixed by a set-screw, to ensure the ram always stopping at the same level, when lowered for moulding each successive tooth. The locking screw S prevents the ram rising from the pressure of ramming the sand. One space of the wheel teeth is then moulded by ramming sand in the space left between the pattern and the edge of the mould previously formed by the strickle board. The locking screw S being then released, the ram carrying the pattern is raised clear of the mould, and is then traversed round through the exact distance of the pitch of the wheel, by means of the dividing handle and the change wheels previously arranged for the required pitch. The segmental pattern is then again lowered, and a second space moulded as before.

When all the teeth have been moulded, the fixing screws of the centre spindle are released, and the whole machine is then lifted away by the foundry crane laying hold of the eye-bolt on the top of the spindle, leaving the mould entirely clear to receive the cores for the arms and boss. The hole in the top of the pedestal is fitted with a cover to keep out the sand, and is then covered over with sand, which protects the pedestal against the action of the hot metal. The centre core for the wheel is adjusted as usual from the circumference, and the cores for the arms are set to their places by means of wood gauges showing the thickness of the arms and rim. The top box is then put on, to cover the mould, being placed in its correct position by the stakes previously mentioned; the runner is then formed, the box duly weighted, and the whole is ready for casting.

This mode of moulding wheels gives the certainty of strict accuracy and excellent finish throughout. The trammel revolving on a secure centre ensures a true circle in the circumference of the teeth; the dividing arrangement ensures the correct relative position of all the teeth; the mode of raising the tooth pattern ensures a gradual steady withdrawal from the sand, whereby the mould is left perfectly finished; the tooth pattern, having but one space from which the whole number of teeth are moulded in succession, produces each tooth an exact duplicate of all the others; and the arrangement for forming the mould and the top box from the same centre produces so good a joint that the occurrence of any fin on the edge of the teeth is prevented. This great superiority in the finish of the wheels moulded by the machine, as compared with hand-moulding from wheel patterns, is accompanied by a very important economy, saving the heavy outlay required for a large stock of costly wheel patterns; thus in the case of a wheel of 6 feet diameter and 12 inches breadth, instead of a complete wheel pattern costing about £10, the whole expense required with the machine, for the tooth segment, core box, and strickling boards, will be only about 15*s*.

The moulding machine now described has the advantages of great compactness and convenience for use, as it occupies but little room; and being used in the foundry floor it effects a great saving in the expensive item of boxes. A special feature of advantage is the portability of the machine, which is a point of great importance; and as a consequence one machine is made to do the work of several, by simply fixing two, three, or more pedestals in different parts of the foundry floor, upon any one of which the machine can be quickly and readily placed for moulding a wheel: whilst those pedestals that are not required at the time are simply covered with sand, leaving the floor in its usual state, clear for other work. By this means the moulding of more than one wheel may be in progress at the same time, with the cost of only one machine in the foundry.

An important practical advantage obtained by machine moulding is the power of manufacturing wheels with an unlimited variety of dimensions, pitch, and forms of teeth, so as to meet exactly the requirements of any case that may occur: thereby avoiding the serious obstacles so frequently experienced of having to modify the intended wheel, in order to suit some existing range of patterns and obviate the serious cost and the delay attending the preparation of a new complete pattern.

As an example of the rapidity of moulding large wheels by means of this machine, it may be mentioned that a bevil wheel of 9 feet diameter and 12 inches breadth, weighing 3 tons, was moulded and cast within four days from the time of the order being given at the North Moor Foundry, Oldham; and in another case at Messrs. Buckley and Taylor's, Oldham, a shrouded bevil wheel of 6 feet diameter and 11 inches breadth was moulded in 24 hours by two men; and a spur wheel of 9 feet diameter and 8 inches breadth, weighing 2 tons, was also moulded in 24 hours by two men.

Mr. Scott exhibited a specimen of the wheel moulding machine, and showed its operation in moulding the teeth of wheels; and also exhibited samples of castings of spur and bevil wheels moulded by the machine.

The Chairman observed that in moulding bevil wheels by the machine the slight taper from the crown to the base of the teeth in the pattern had the effect of easing the pattern from the sand at the moment of beginning to withdraw it, and caused it to clear the mould at once, so that there would not be any risk of shaking or disturbing the tooth which had been last moulded in the previous operations; but in the case of spur wheels, where the pattern had not this advantage of easing itself from the sand in withdrawing, he enquired whether any difficulty had been experienced from the hinder tooth of the pattern interfering during the withdrawal with the truth of the tooth last moulded.

Mr. Scott replied that all risk of damage from that source in the moulding of spur wheels was provided against by making both the teeth of the pattern with a little taper on their outer side, so that the pattern did not touch the last moulded tooth except just at the level of the top of the mould, and cleared itself immediately it began to be withdrawn. There was thus no second smoothing of the sides of the sand teeth after moulding each tooth in the first instance.

The Chairman enquired how many of the machines were now in use, and what was the cost of the two sizes of machine mentioned in the paper.

Mr. Scott replied that there were now sixty of the machines in use, since their first introduction about 2½ years ago; and the cost was about £90 for the smaller sized machine, for moulding wheels from 12 inches to 5 feet diameter, and £120 for the larger size, for diameters from 20 inches to 12 feet. The object of the machine was to enable all engineers to make their own wheels on their own premises at a very small outlay, and exactly in accordance with the requirements of any case that might occur.

Mr. E. A. Cowper said he had seen this wheel moulding machine at Messrs. Maudslay and Field's works in London, where it had been in use for several months; and he understood that it was in constant use in the foundry and had proved completely satisfactory in working. He had himself experienced the great advantage of obtaining toothed wheels moulded by machinery, instead of by a pattern drawn by hand, on account of the superior accuracy thereby obtained in the teeth; and by the machine described in the paper this advantage could now be obtained in all iron foundries. In regard to the mode of preparing the bottom part of the mould by means of the strickling board before beginning to mould the teeth, as described in the paper, he supposed that in afterwards moulding the teeth it was requisite to break up the smooth face of the sand at the time of moulding each tooth, in order to ensure the new sand in the tooth binding with that in the mould previously smoothed.

Mr. **Scott** said that in moulding each tooth the face of the old sand was disturbed, which made the fresh sand in the tooth unite completely with it.

Mr. H. H. **Grierson** observed that, although in the case of only one or two castings being required from the same pattern it might be preferable to mould by the machine from the small pattern, moulding only a single tooth at a time, he thought that when three or more castings were wanted from the same pattern it would be found more profitable to make a complete pattern for the purpose, on account of the saving then effected in cost of labour and in the time of moulding, by getting a number of moulders at work simultaneously round the circumference of the complete pattern. Under such circumstances he thought the only advantage attending the machine would be in drawing the pattern by mechanical means instead of by hand.

Mr. H. **Woods** thought that, even if a complete wheel pattern were drawn from the sand by a machine instead of by hand, it was a question whether it could be drawn as well as the small pattern containing only the space for a single tooth; and he considered there was always a great deal more liability to a break-down in the mould in drawing a complete pattern.

Mr. W. **Ford Smith** considered that wood patterns should not under any circumstances be used for moulding toothed wheels, on account of their liability to continual change of shape, arising from variations in the humidity and temperature of the atmosphere, which caused the different pieces of wood composing the pattern to warp and shrink, principally across the grain of the wood. For small wheel castings up to a certain size he considered it desirable to mould the wheels from machine-cut metal patterns correctly turned; and above the size at which the patterns became too unwieldy to draw readily from the sand, the next step should be to employ a moulding machine that would produce a perfectly cylindrical or concentric mould, free also from any irregularity or twist. The accuracy of metal patterns was not affected by changes of the atmosphere; but even with these it was advisable to draw them from the sand by some mechanical means.

Mr. H. Woods observed that the dividing disc for spacing out the teeth of the wheel in the mould appeared rather small in diameter for moulding wheels of large size; and he enquired whether any difficulty was ever found to arise in spacing out the teeth correctly round the circumference of a large wheel, as a very slight error in the spacing of each tooth would become a serious amount when multiplied by a large number of teeth. He asked also whether the accuracy of spacing was dependent in any way upon the eyesight or skill of the moulder using the machine.

Mr. Scott replied that the dividing disc and the several change wheels were carefully tested in the construction of each machine, so as to ensure the correct spacing of each tooth round the entire circle; and a list was furnished with the machine of the arrangement of change wheels and the number of turns to be given to the handle on the dividing disc for the pitch of every size of wheel required to be moulded within the range of the machine. Except by alterations of the change wheels and of the number of turns on the dividing disc, the moulder had no means of altering the spacing of the teeth; and the accuracy of the spacing was therefore not dependent upon his skill in using the machine. A second tooth could not be moulded unless the pattern went down into its place correctly after the previous tooth was completed; so that any error in turning the dividing handle was at once apparent.

With regard to the relative economy of moulding from the small pattern segment or from a complete wheel pattern, where a number of castings were required from the same pattern, he had had as many as 32 bevil wheels made from one of the segment patterns, and had found the cost had been less than if a complete pattern of the whole wheel had been made for the purpose, taking into consideration the wear and tear of the moulding machine on the one hand, and on the other the rental for the storage of a stock of complete wheel patterns. There was besides this the advantage that the castings moulded by the machine were superior in accuracy, both as regarded the pitch of the teeth and the truly circular shape of the circumference of the wheel.

Mr. H. H. GRIERSON did not think the castings moulded by the machine were superior in accuracy to those moulded from patterns having the teeth cut by machinery; and the actual moulding of the teeth would evidently occupy a longer time in moulding from the segment pattern of only a single tooth than when a complete pattern was used with a number of moulders at work upon it simultaneously. He understood that a difficulty had been experienced in some cases in introducing the moulding machine, from the men objecting to work with it; and he enquired how far that had been the fact.

Mr. SCOTT said he had not heard of any difficulty from that source, nor had any objection arisen against the use of the machine in any instance that he was acquainted with. As to the time occupied in moulding by the machine, he had found that in moulding wheels with box arms of H section, which involved extra work in the ordinary way of moulding, the total men's time occupied upon the entire wheel was not greater with the machine than with a complete pattern, though of course the moulding would be done with more expedition where a number of moulders could work simultaneously upon it.

Mr. W. LLOYD enquired whether an ordinary moulder would be able to work the machine without special instruction for the purpose.

Mr. SCOTT replied that any moulder was able to use the machine at once, and the machines had been introduced at various foundries without giving the men any instructions how to work them, except as regarded the alterations of the change wheels for different sizes of castings.

Mr. E. A. COWPER said that in the case of the moulding machine supplied to Messrs. Maudslay he understood it was got to work on the same day that it was received, without any difficulty whatever being experienced.

The CHAIRMAN observed that, although the use of complete patterns for toothed wheels might still continue general, the machine gave a ready means of moulding wheels with great accuracy, and apparently with as much economy in labour as if a complete pattern were employed.

He proposed a vote of thanks to Mr. Scott for his paper, which was passed.

The Meeting then terminated.

Fig. 1. *Vertical Section of Accumulator.*

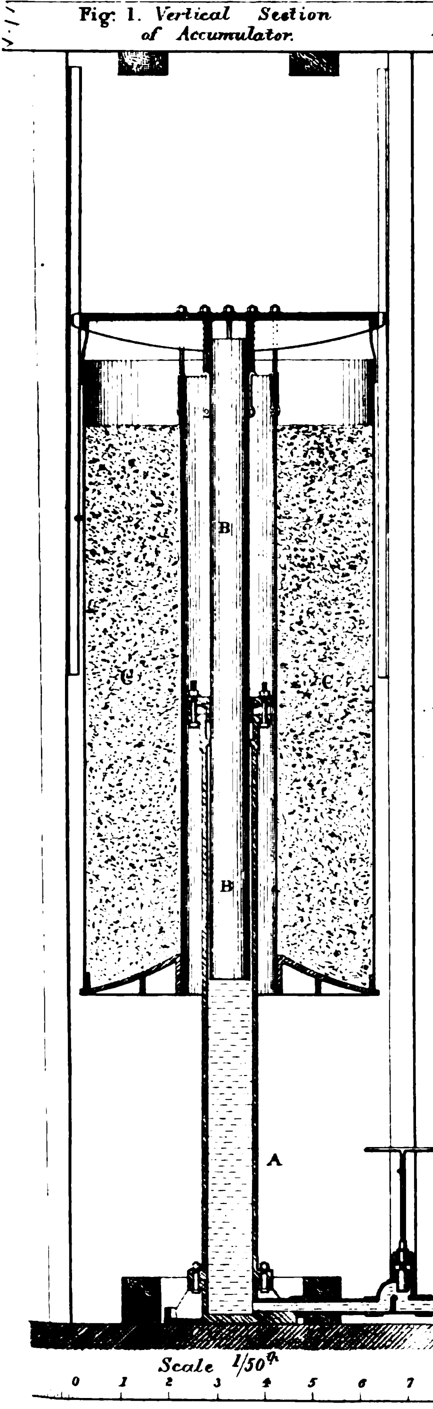
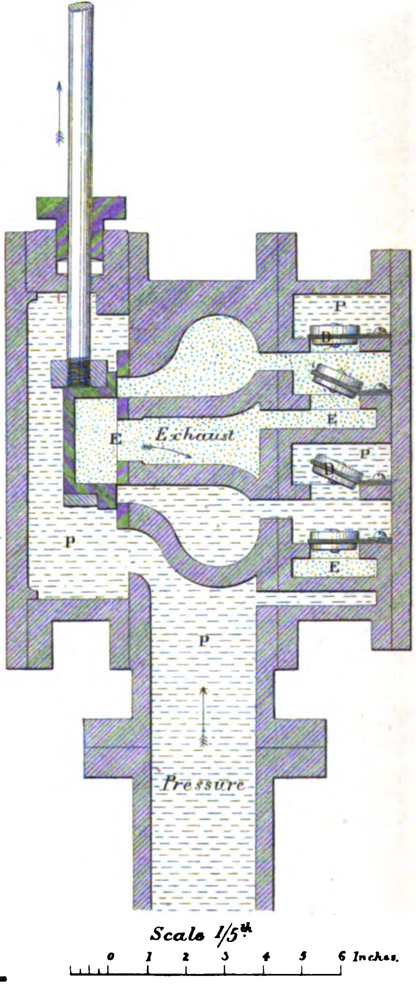


Fig. 2. *Section of Slide Valve and Relief Valves for Hydraulic Cranes, &c.*



(Proceedings Inst. M.E. 1868)

WATER PRESSURE MACHINERY.

Plate 2.

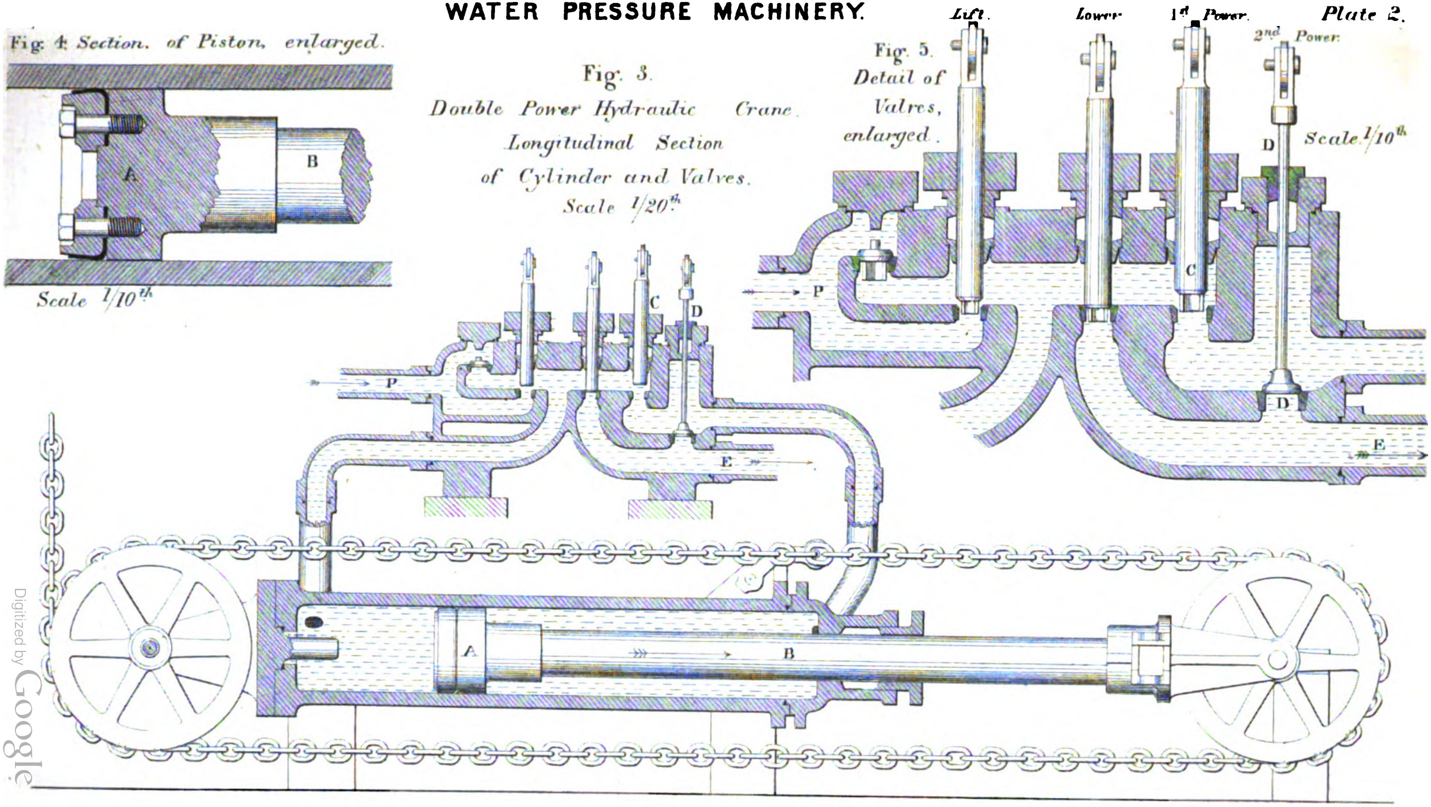


Fig. 4. Section of Piston, enlarged.

Scale 1/10th

Fig. 3.
Double Power Hydraulic Crane.
Longitudinal Section
of Cylinder and Valves.
Scale 1/20th

Fig. 5.
Detail of
Valves,
enlarged.

Scale 1/10th

(Proceedings Inst. M.E. 1868)

Single-power Platform Crane for railway goods stations.

Fig. 6. *Elevation.*

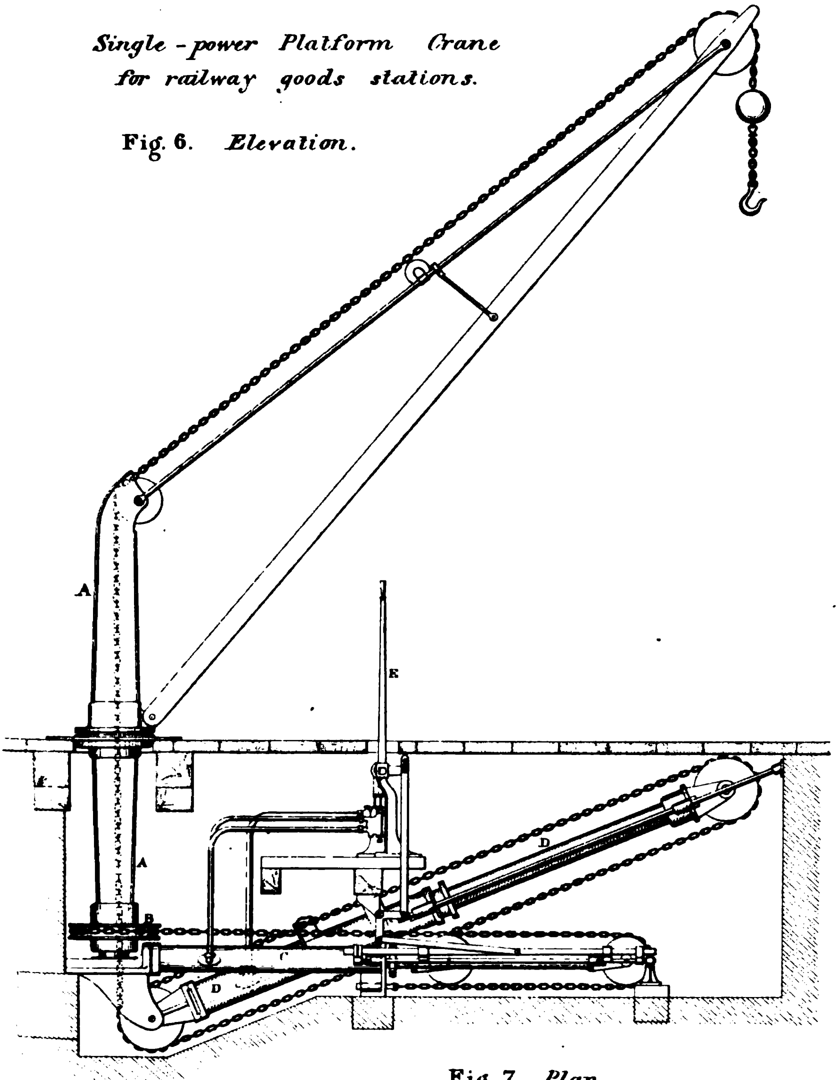
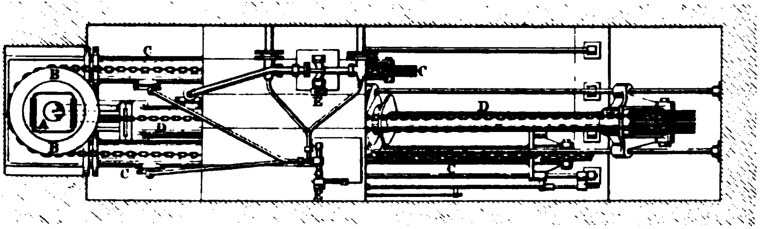


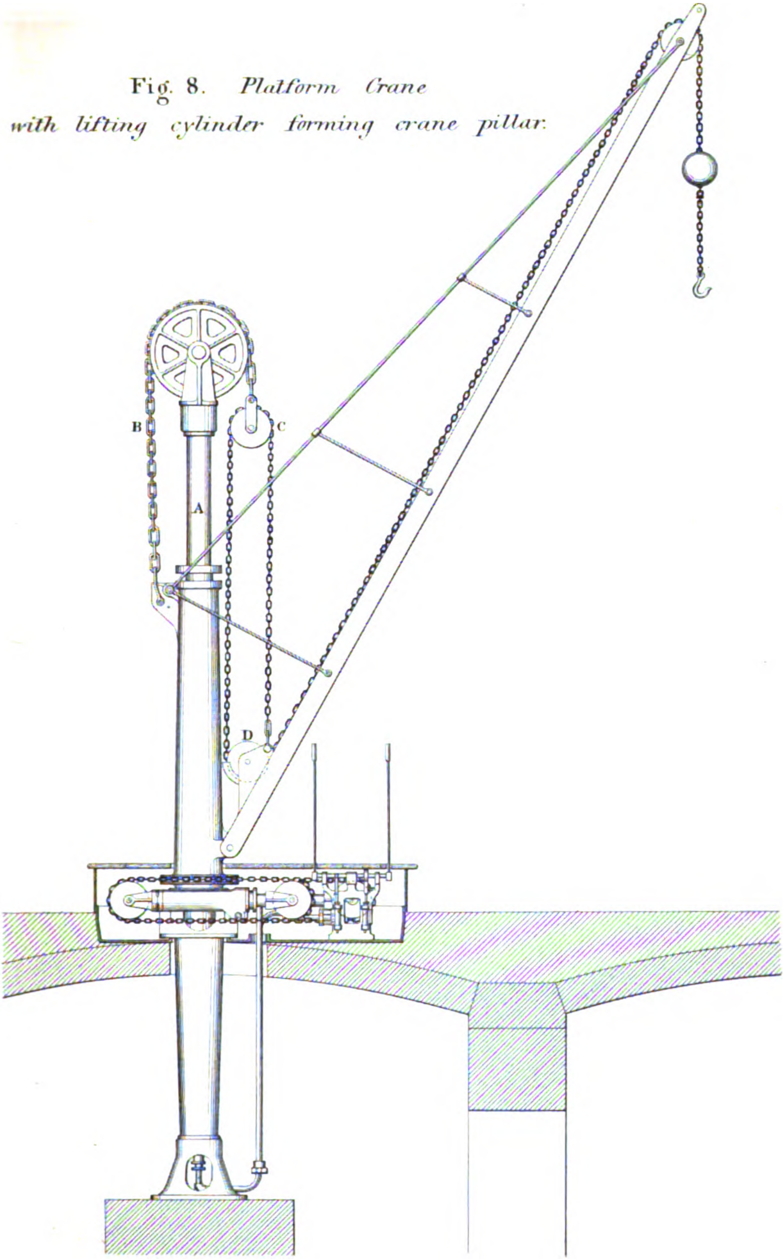
Fig. 7. *Plan.*



Scale 1/50 th

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 *Feet.*

Fig. 8. *Platform Crane with lifting cylinder forming crane pillar.*



(Proceedings Inst. M. E. 1868.)

Scale 1/60th

WATER PRESSURE MACHINERY. *Plate 5.*

Simplest form of Hydraulic Crane, without turning power.

ig. 9.

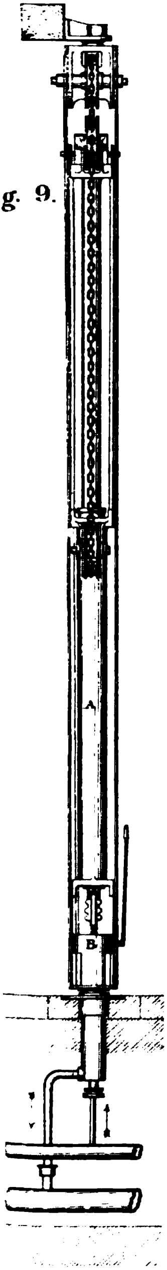
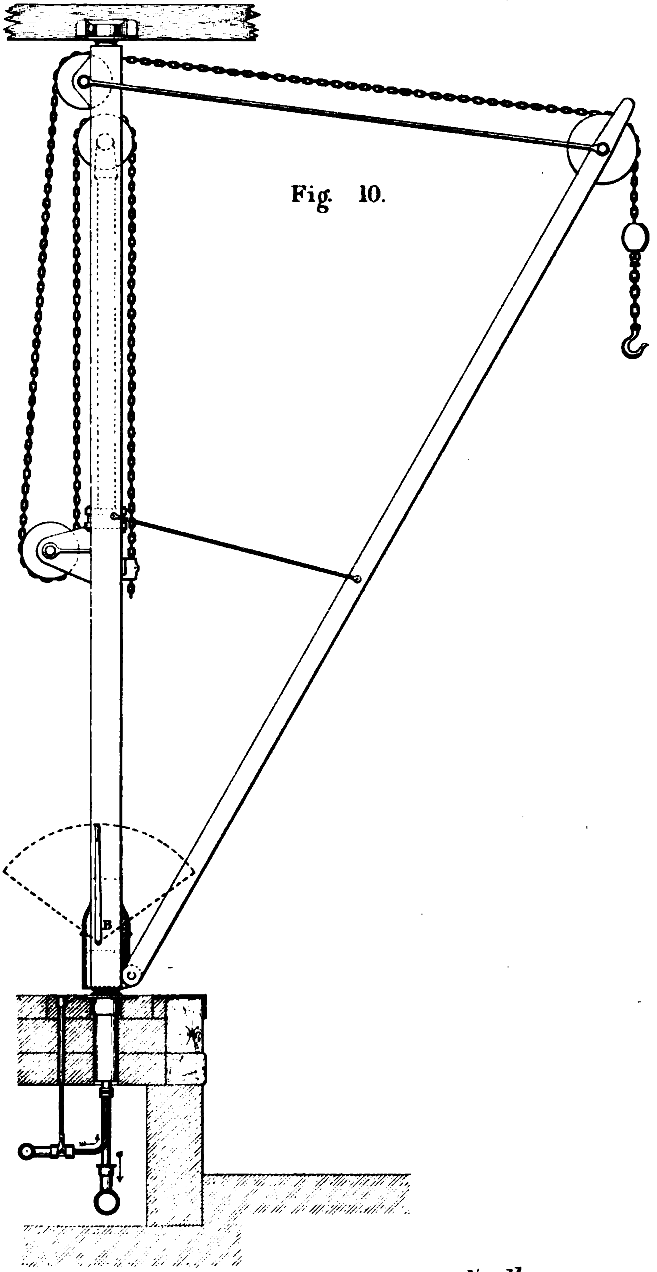


Fig. 10.



(Proceedings Inst. M.E. 1868.)

Scale 1/50th.

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 *Feet.*

WATER PRESSURE MACHINERY. *Plate 6.*

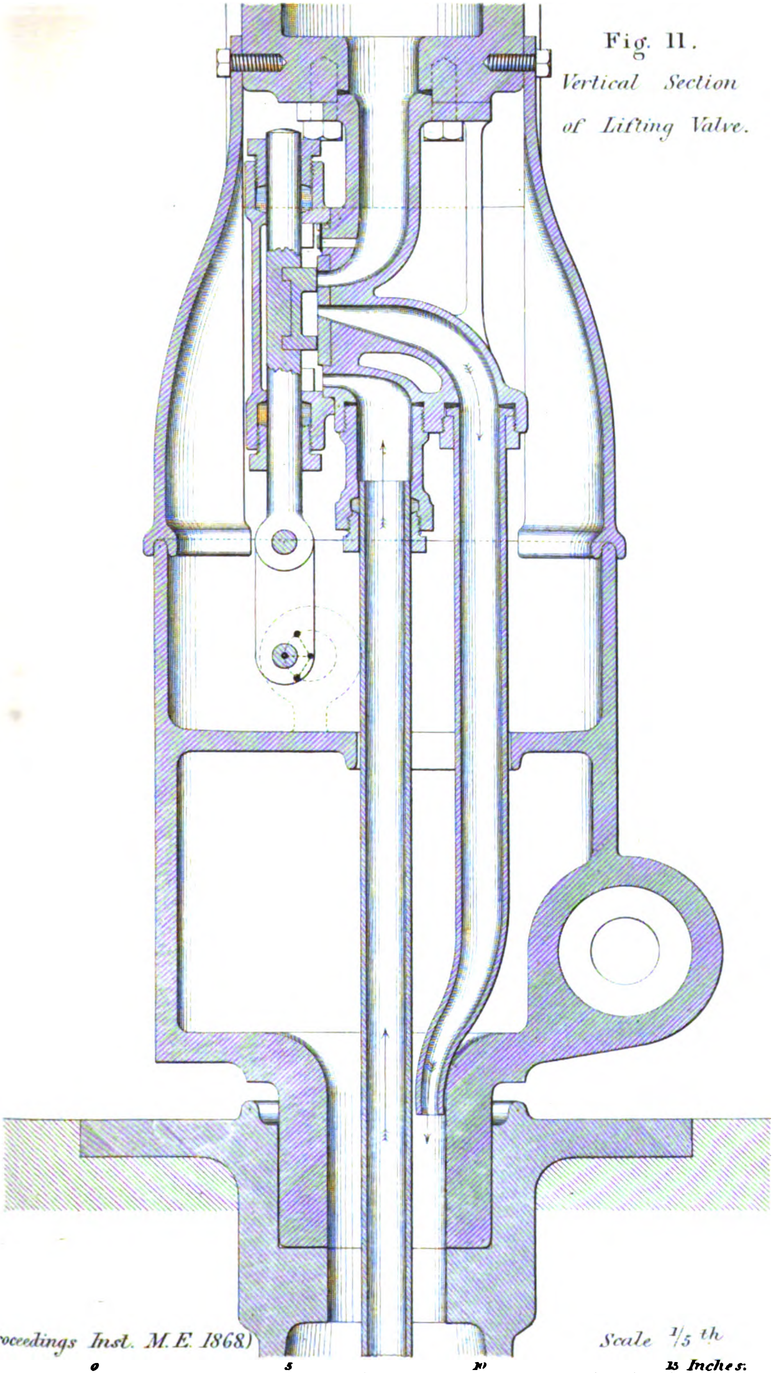


Fig. 11.
Vertical Section of Lifting Valve.

(Proceedings Inst. M.E. 1868)

Scale 1/5 th

WATER PRESSURE MACHINERY.

Fig. 12. *Side Elevation of Forge and Foundry Crane.*

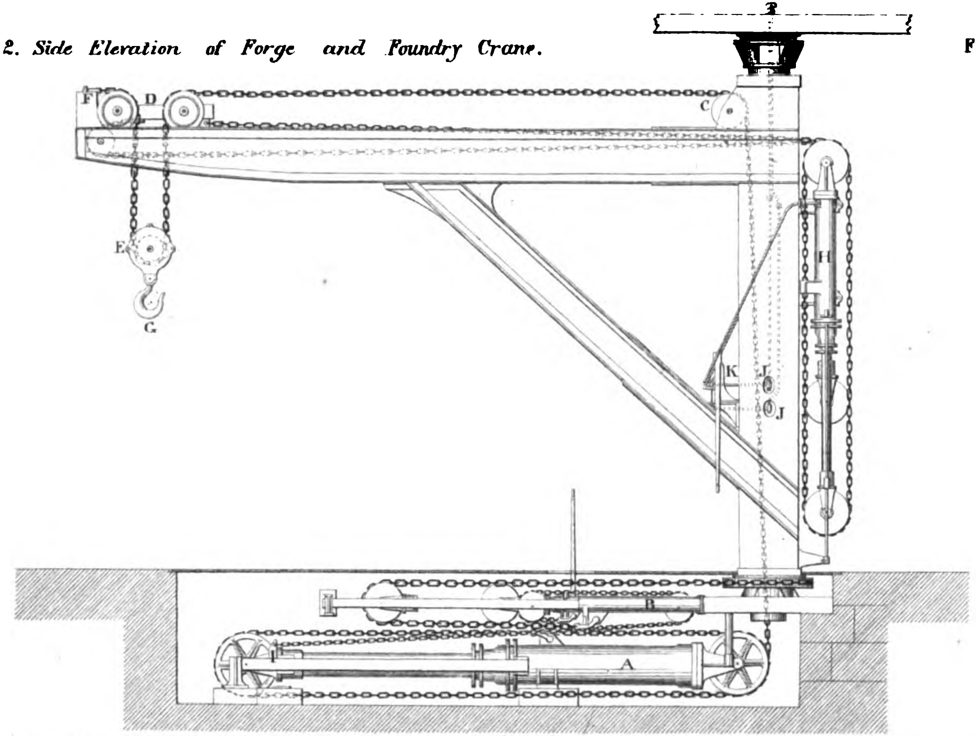
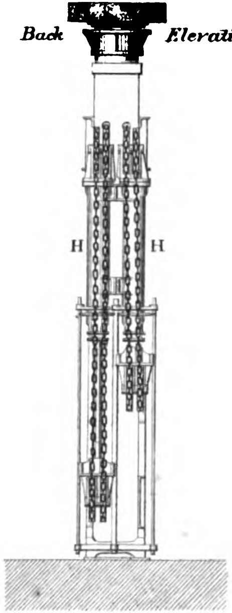


Fig. 13. *Back Elevation.*

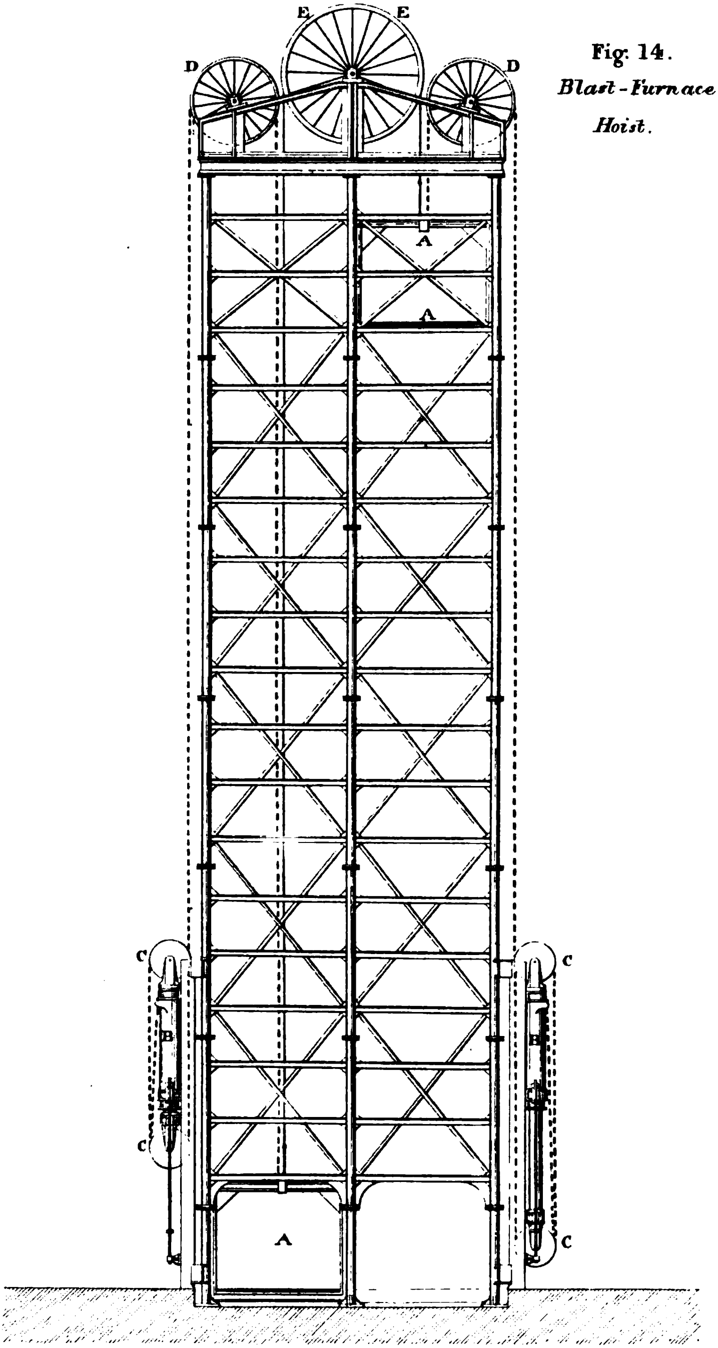


(Proceedings Inst. M.E. 1868)

Scale 1/100th 10 5 0 10 20 *Feet.*

Fig. 14.

Blast-Furnace Hoist.



(Proceedings Inst. M.E. 1868) *Scale 1/160th.*

10 5 0 10 20 30 40 Feet.

ALLEN ENGINE AND GOVERNOR.

Plate 9.

Fig. 1. *Side Elevation, with Section of Air-pump.*

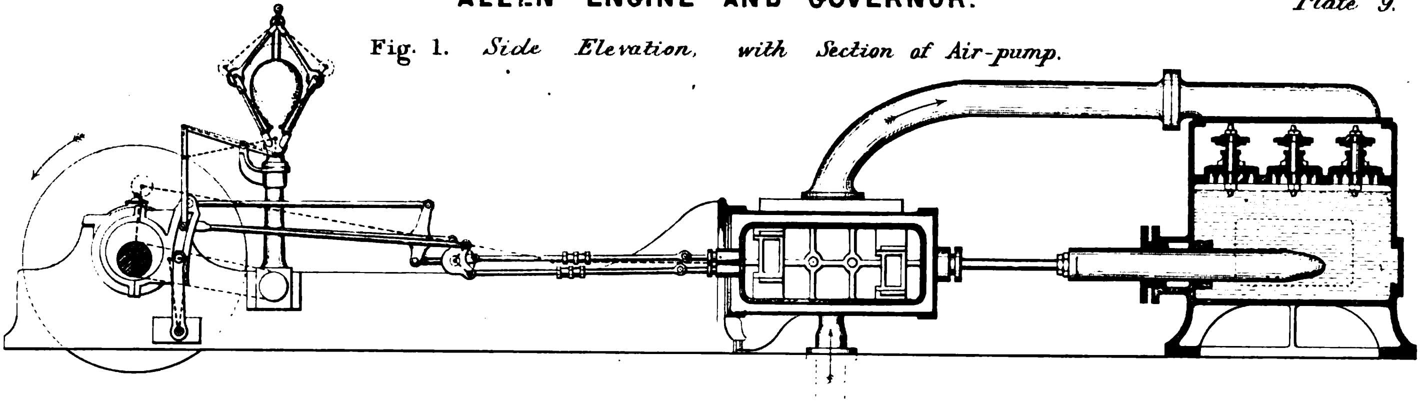
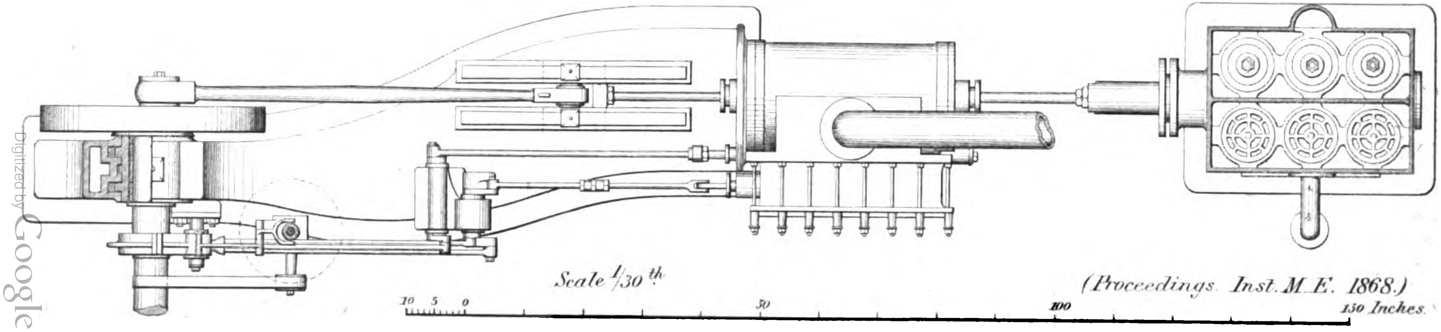


Fig. 2. *Plan.*



Scale 1/30th.

(Proceedings. Inst. M. E. 1868.)

ALLEN ENGINE AND GOVERNOR.

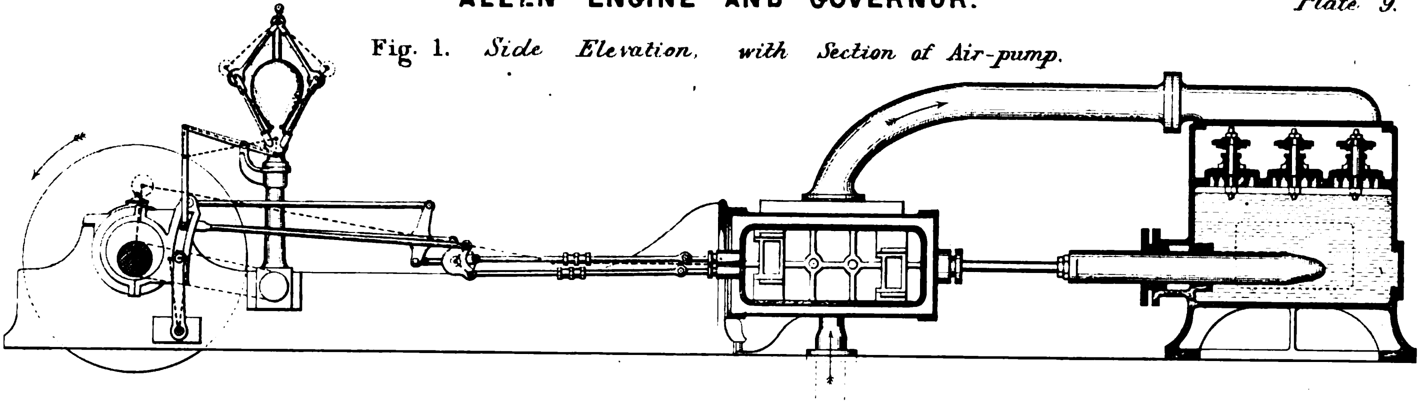


Fig. 1. *Side Elevation, with Section of Air-pump.*

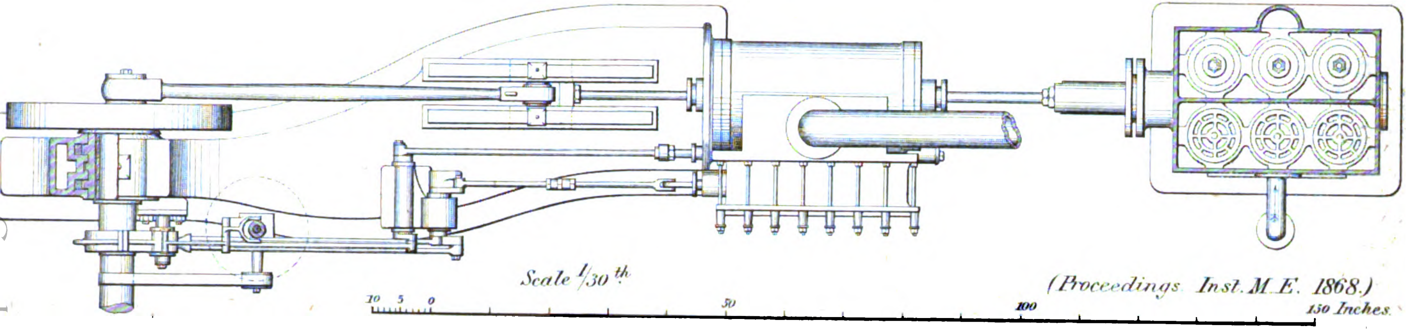


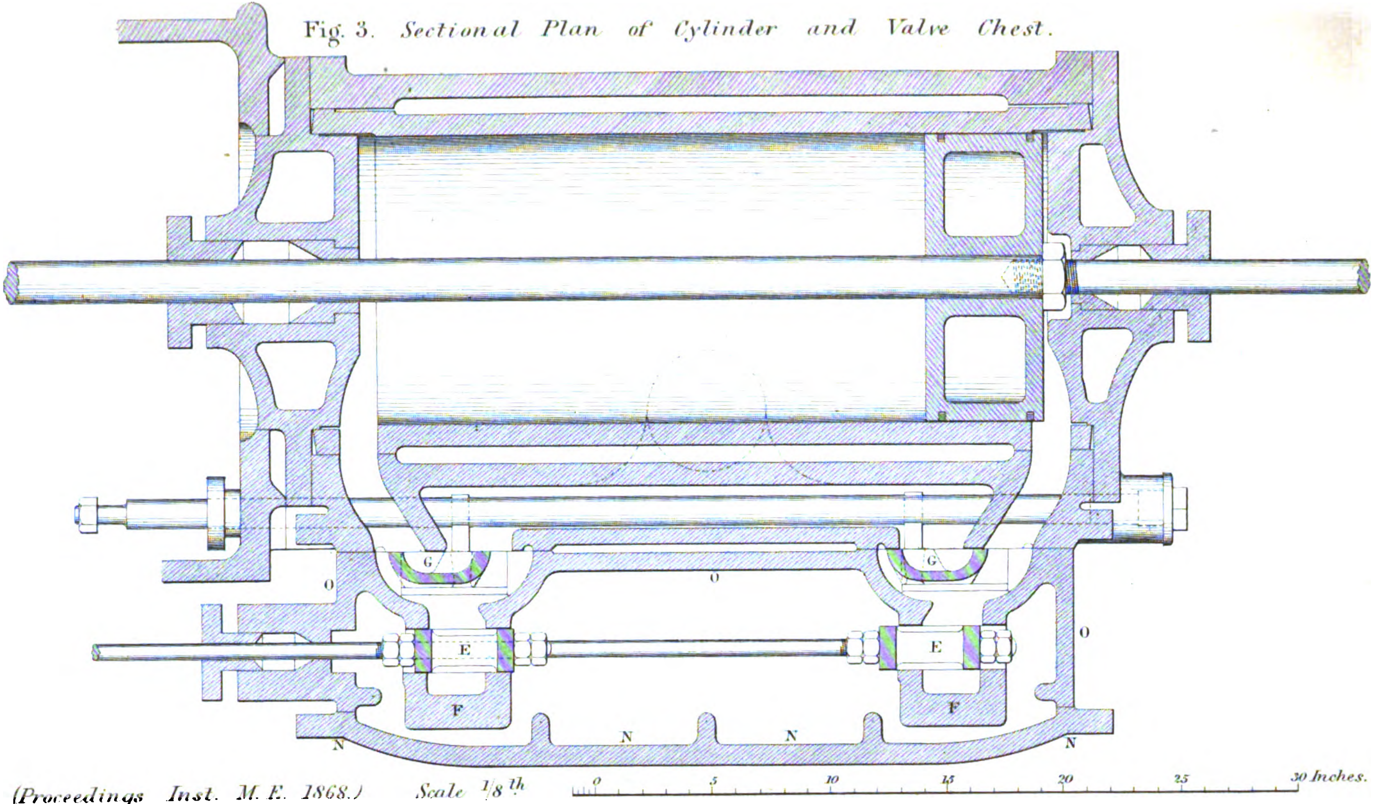
Fig. 2. *Plan.*

(Proceedings Inst. M. E. 1868.)

ALLEN ENGINE AND GOVERNOR.

Plate 10.

Fig. 3. *Sectional Plan of Cylinder and Valve Chest.*



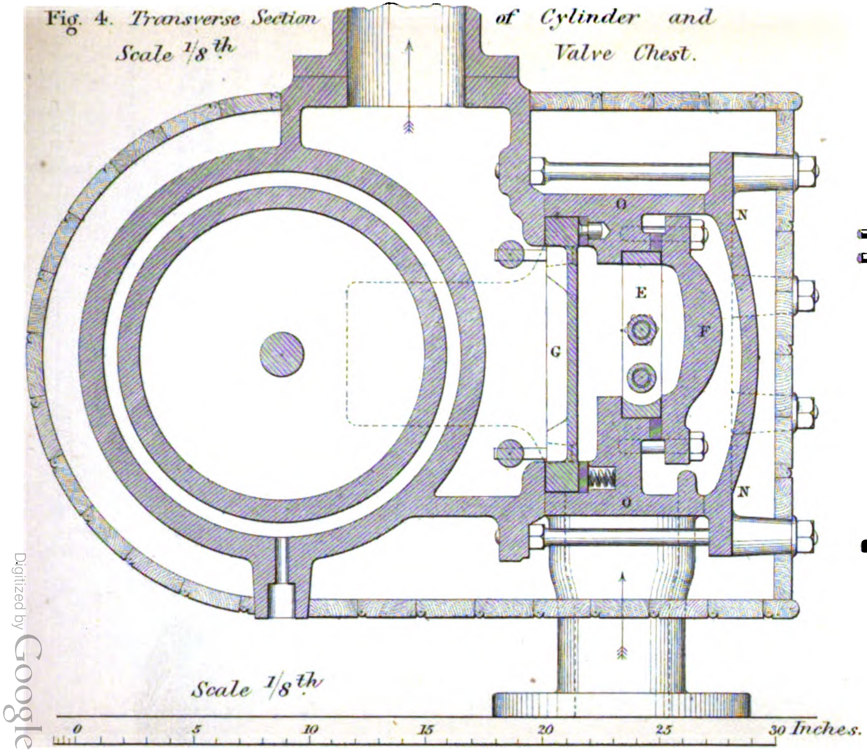
(Proceedings Inst. M. E. 1868.) *Scale 1/8th*

ALLEN ENGINE AND GOVERNOR.

Plate 11.

Fig. 4. Transverse Section of Cylinder and Valve Chest.

Scale 1/8th.



Elevations of Port Faces.

Scale 1/16th.

Fig. 5. Steam Ports.

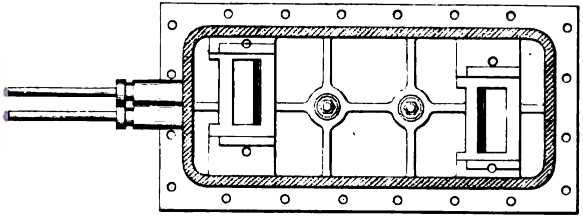
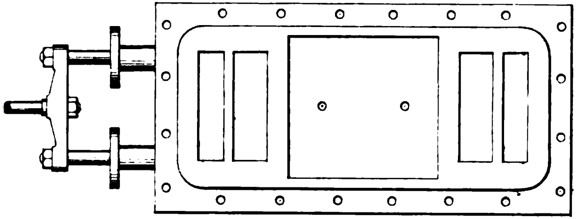


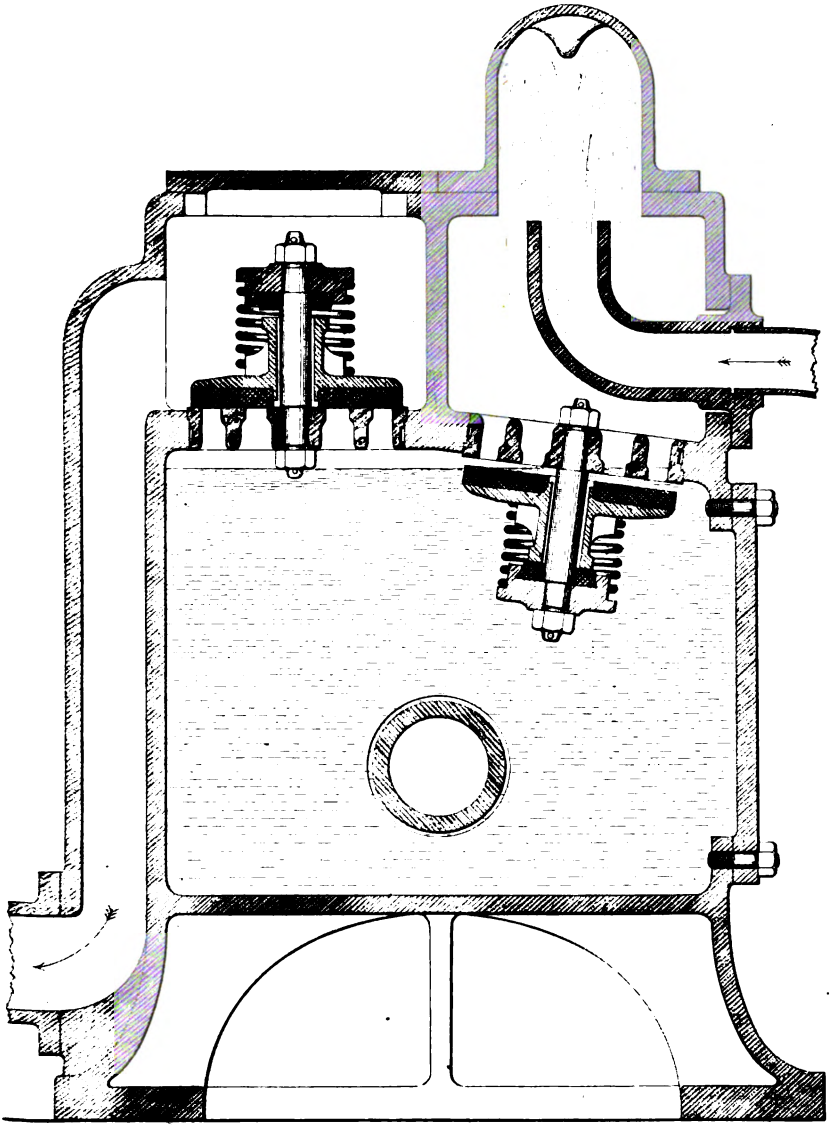
Fig. 6. Exhaust Ports.



Scale 1/16th.

(Proceedings Inst. M. E. 1868.)

Fig. 7. *Transverse Section of Condenser and Air-pump.*



(Proceedings Inst. M.E. 1868)

Scale 1/8th.

ALLEN ENGINE AND GOVERNOR. *Plate 13.*

Elevations of Governor.

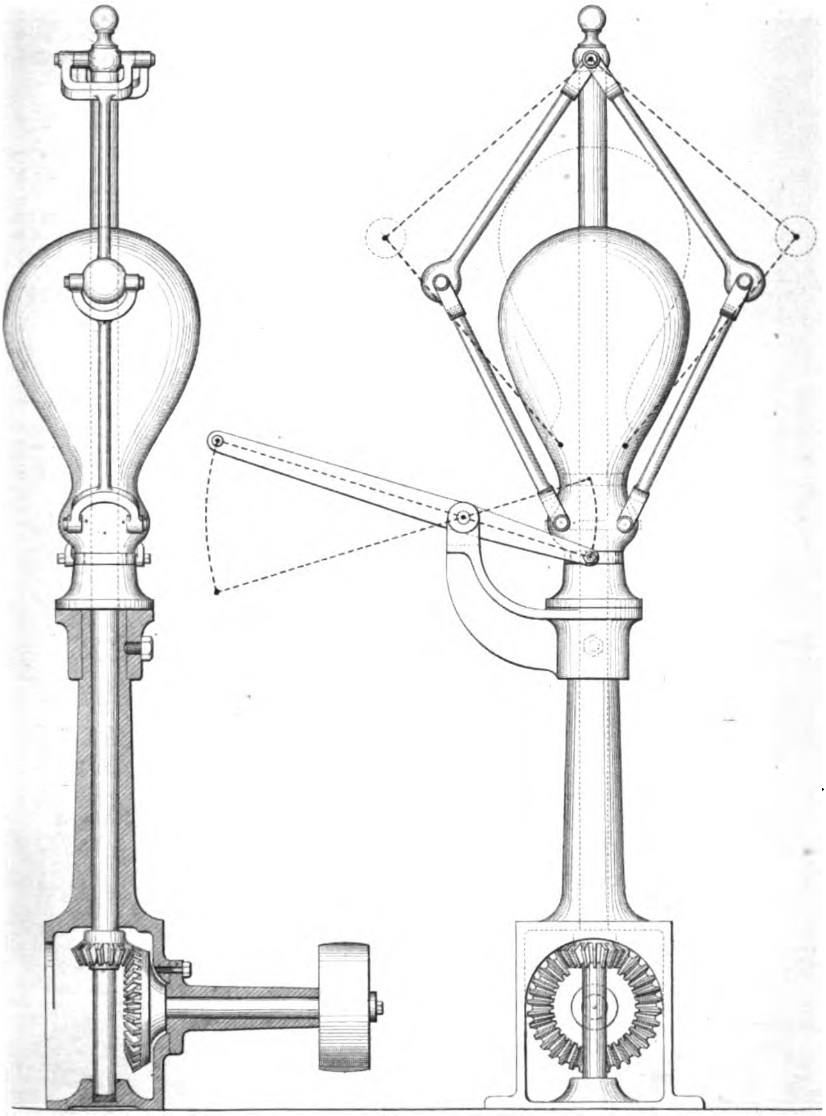


Fig. 8.

Fig. 9.

(Proceedings Inst. M.E. 1868)

Scale 1/8th.

ALLEN ENGINE AND GOVERNOR.

Plate 14.

Valve Gear.

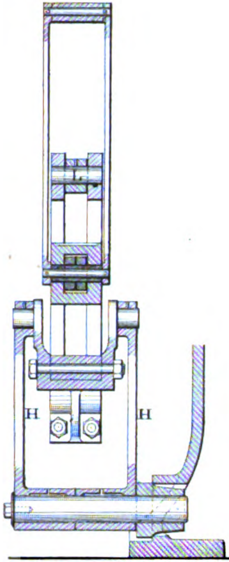


Fig. 10. *Transverse Section.*

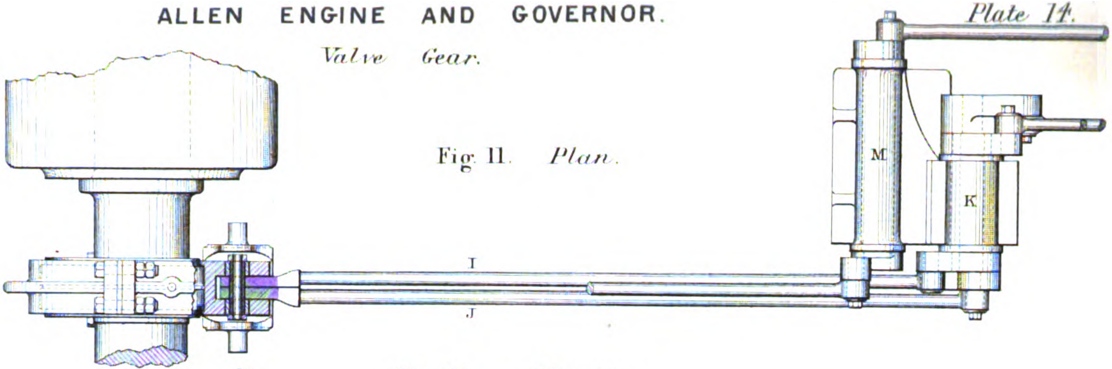


Fig. 11. *Plan.*

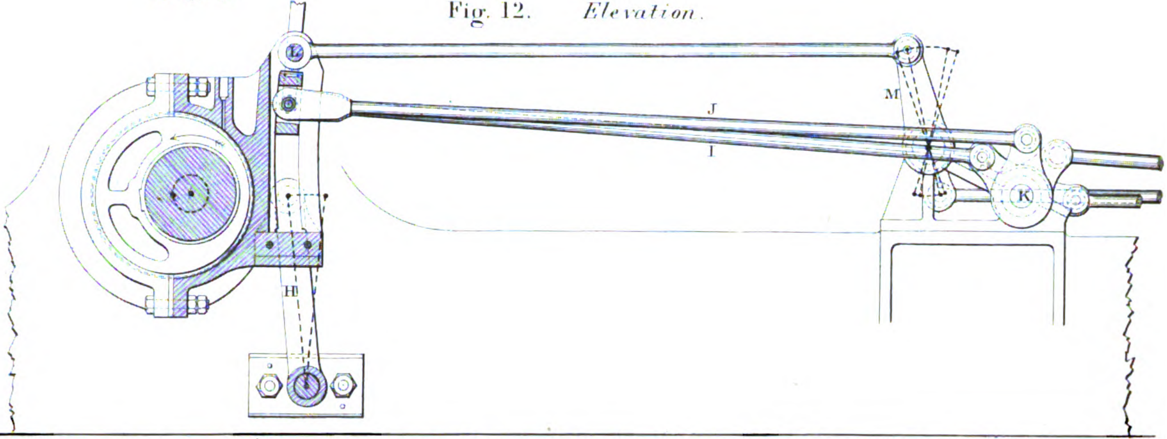


Fig. 12. *Elevation.*

(Proceedings Inst. M.E. 1868.) Scale 1/12 th.

Plate 15.

ALLEN ENGINE AND GOVERNOR.

Valve Motion,

the reference letters indicating corresponding positions throughout.

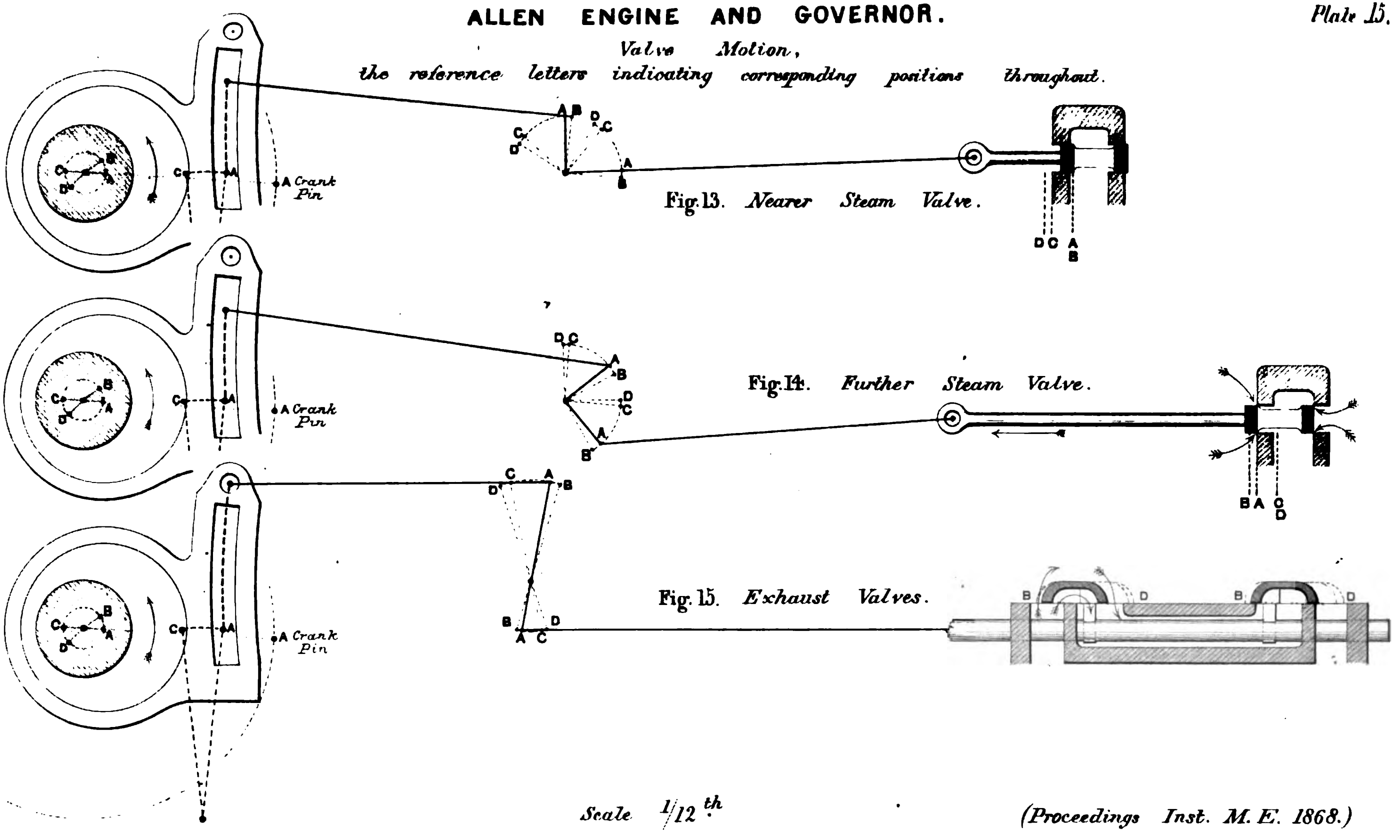


Fig. 13. Nearer Steam Valve.

Fig. 14. Further Steam Valve.

Fig. 15. Exhaust Valves.

Scale 1/12th.

(Proceedings Inst. M. E. 1868.)

ALLEN ENGINE AND GOVERNOR.

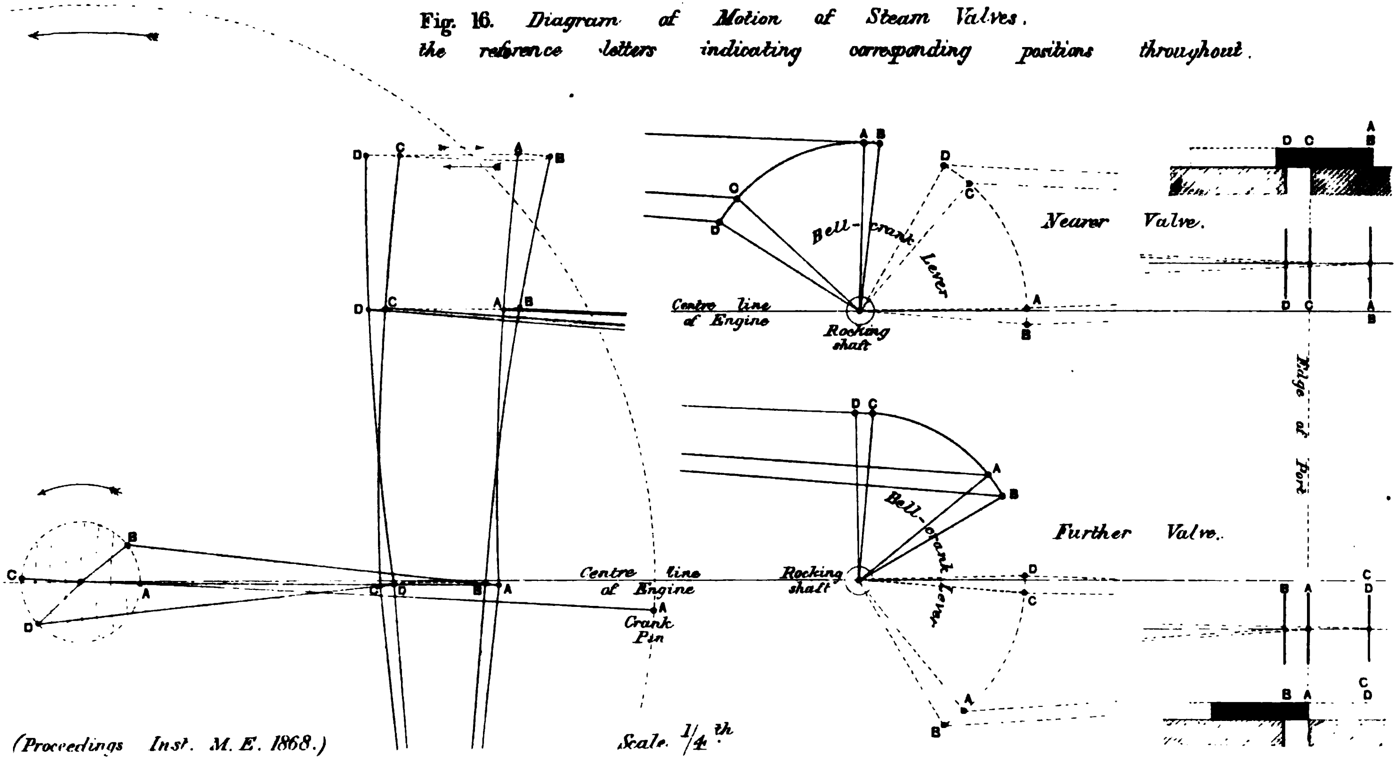


Fig. 16. *Diagram of Motion of Steam Valves, the reference letters indicating corresponding positions throughout.*

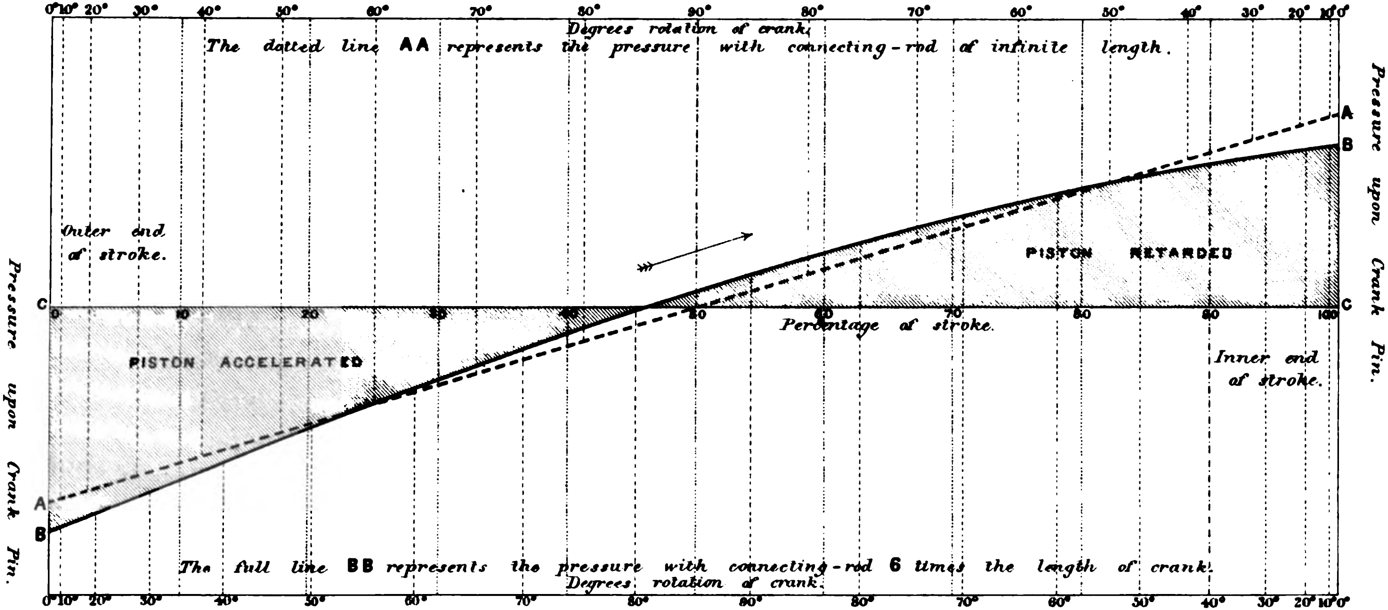
(Proceedings Inst. M. E. 1868.)

Scale 1/4th

Plate 17.

ALLEN ENGINE AND GOVERNOR.

Fig. 17. *Diagram showing Pressure upon Crank Pin, produced by the inertia of the horizontal reciprocating parts during their acceleration, and retardation in each half of the stroke.*



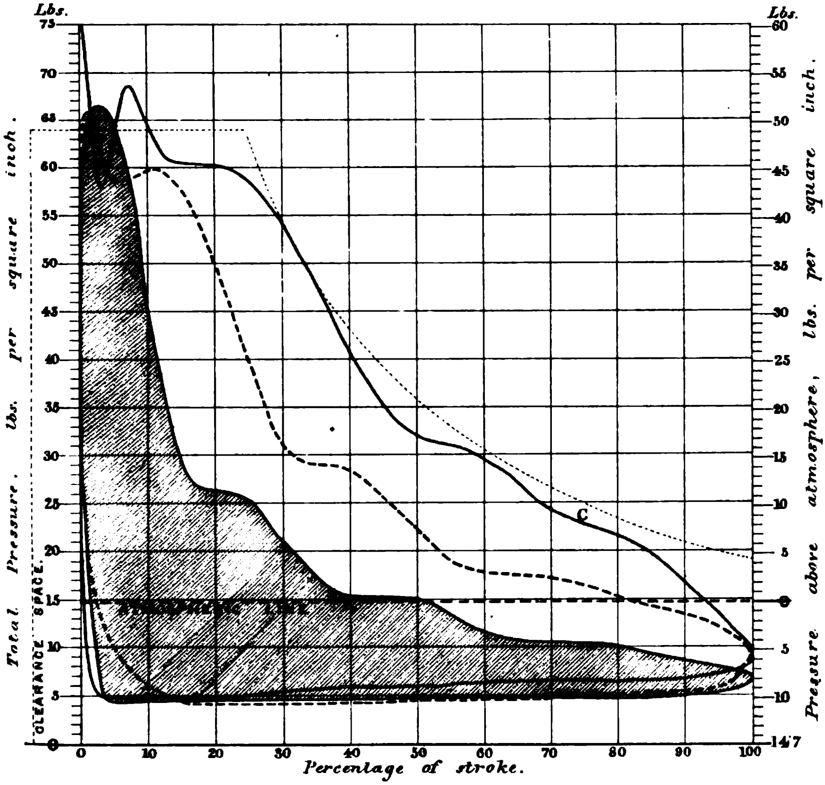
(Proceedings Inst. M.E. 1868.)

Fig. 18. *Indicator Diagrams from Allen Engine.*

Cylinder 12 *ins. diam.,* 24 *ins. stroke.*

200 *Revolutions per minute.*

Speed of Piston 800 *feet per minute.*



The fine dotted line shows the theoretical true expansion curve of the indicator diagram C.

(Proceedings Inst. M. E. 1868.)

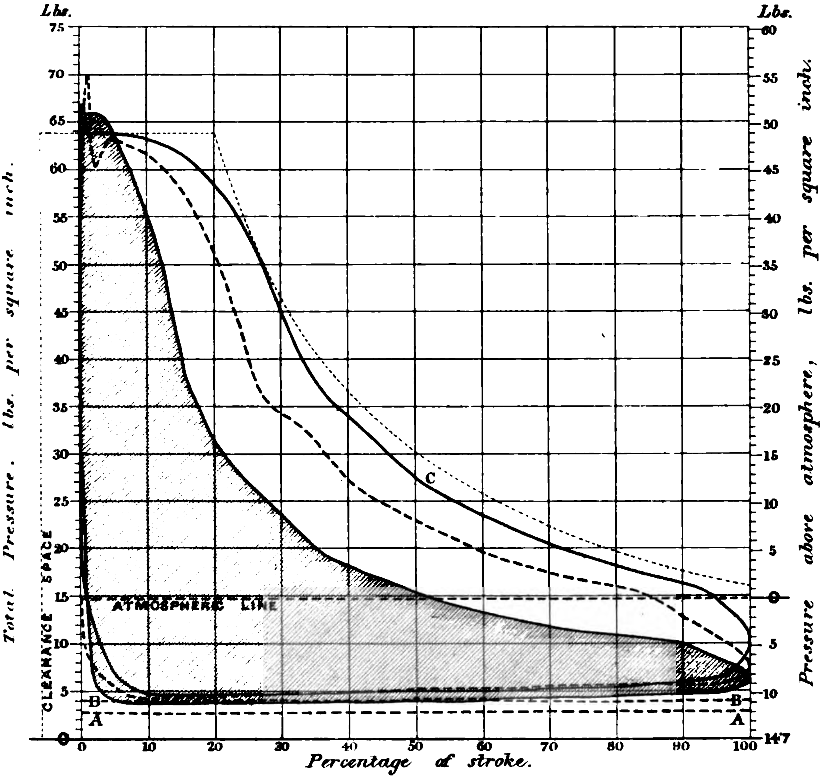
ALLEN ENGINE AND GOVERNOR. *Plate 19.*

Fig. 19. *Indicator Diagrams from Allen Engine.*

Cylinder 18 *ins. diam.,* 30 *ins. stroke.*

120 *Revolutions per minute.*

Speed of Piston 600 *feet per minute.*



AA *vacuum in condenser* } *at the time of taking the*
BB . .. *exhaust chamber* } *dotted indicator diagram.*

The fine dotted line shows the theoretical true expansion curve of the indicator diagram C.

(Proceedings Inst. M. E. 1868.)

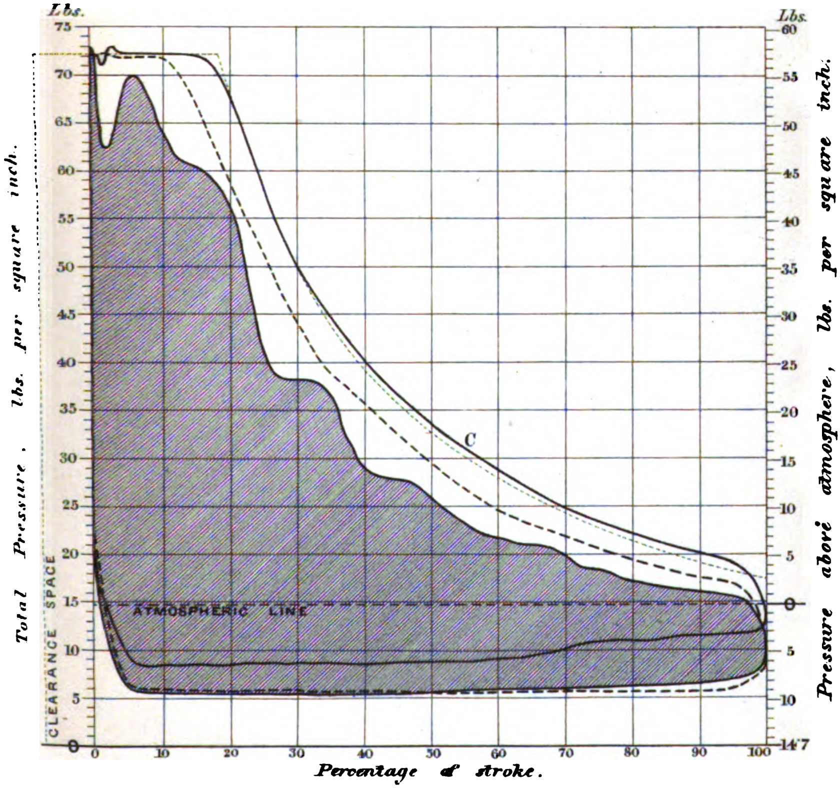
ALLEN ENGINE AND GOVERNOR. *Plate 20.*

Fig. 20. *Indicator Diagrams from Allen Engine.*

Cylinder 20 *ins. diam.,* 36 *ins. stroke.*

100 *Revolutions per minute.*

Speed of Piston 600 *feet per minute.*

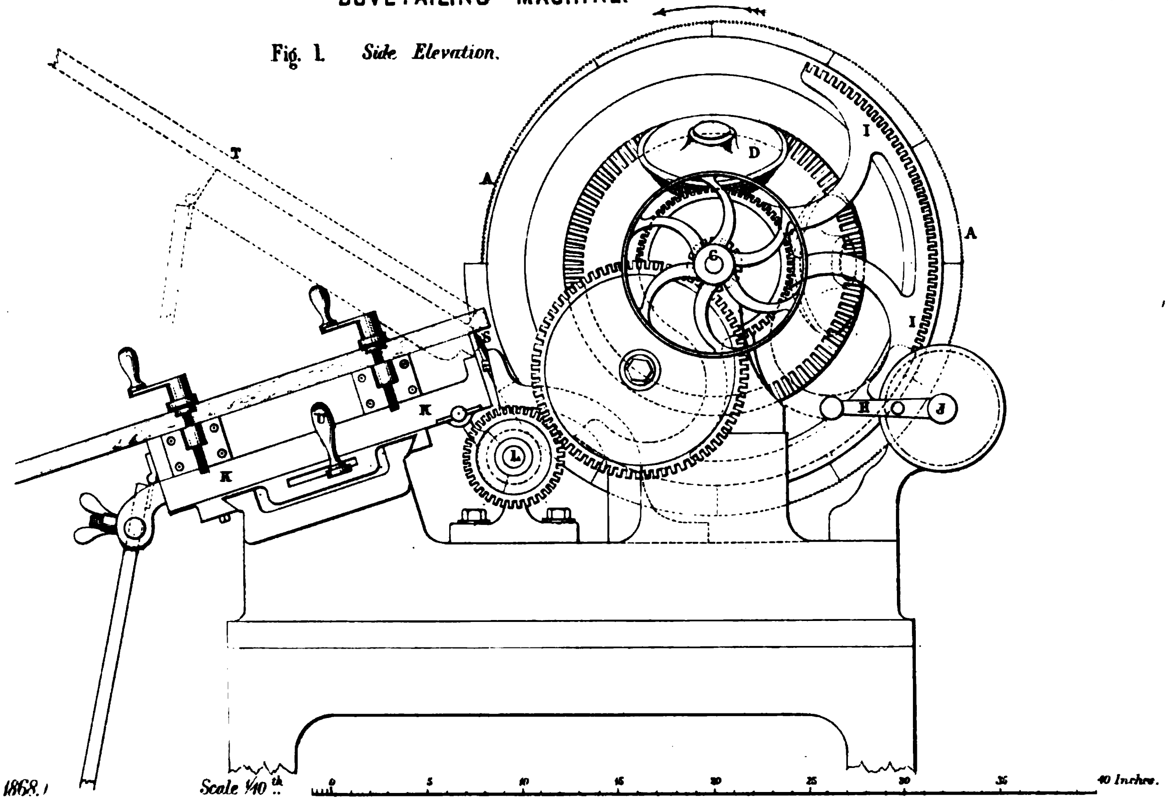


The fine dotted line shows the theoretical true expansion curve of the indicator diagram C.

(Proceedings Inst. M. E. 1868.)

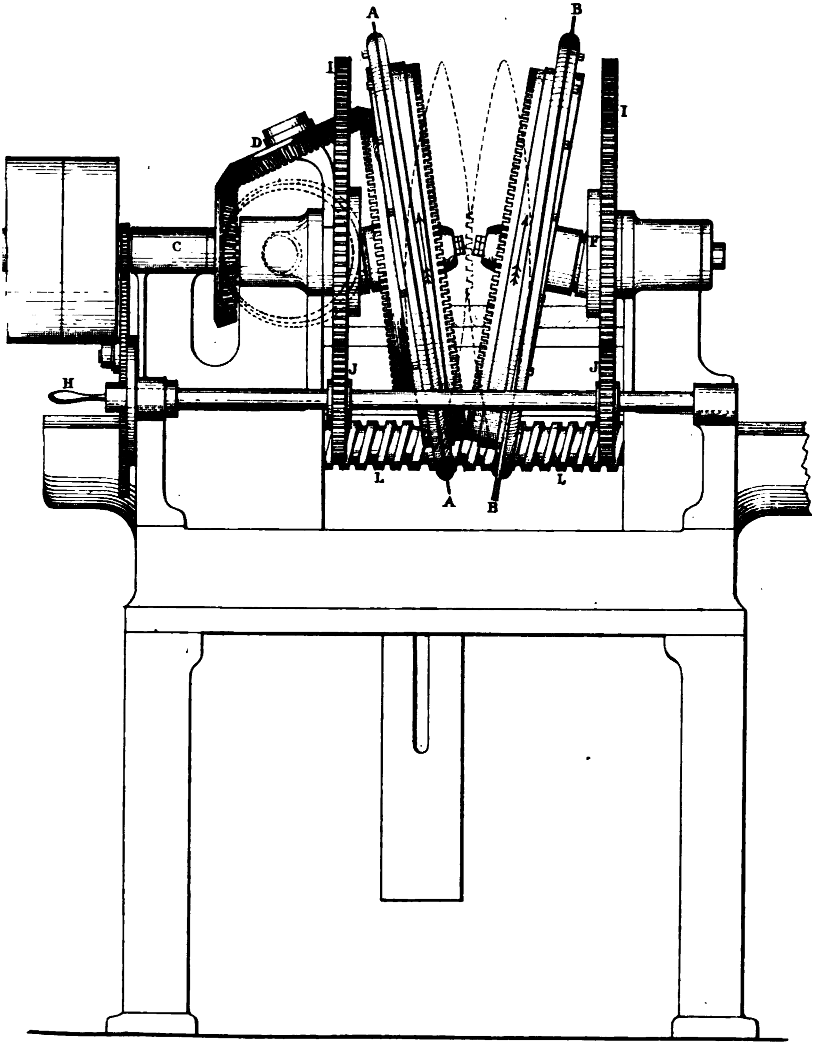
DOVETAILING MACHINE.

Fig. 1. *Side Elevation.*



DOVETAILING MACHINE.

Fig. 2. *Back Elevation.*



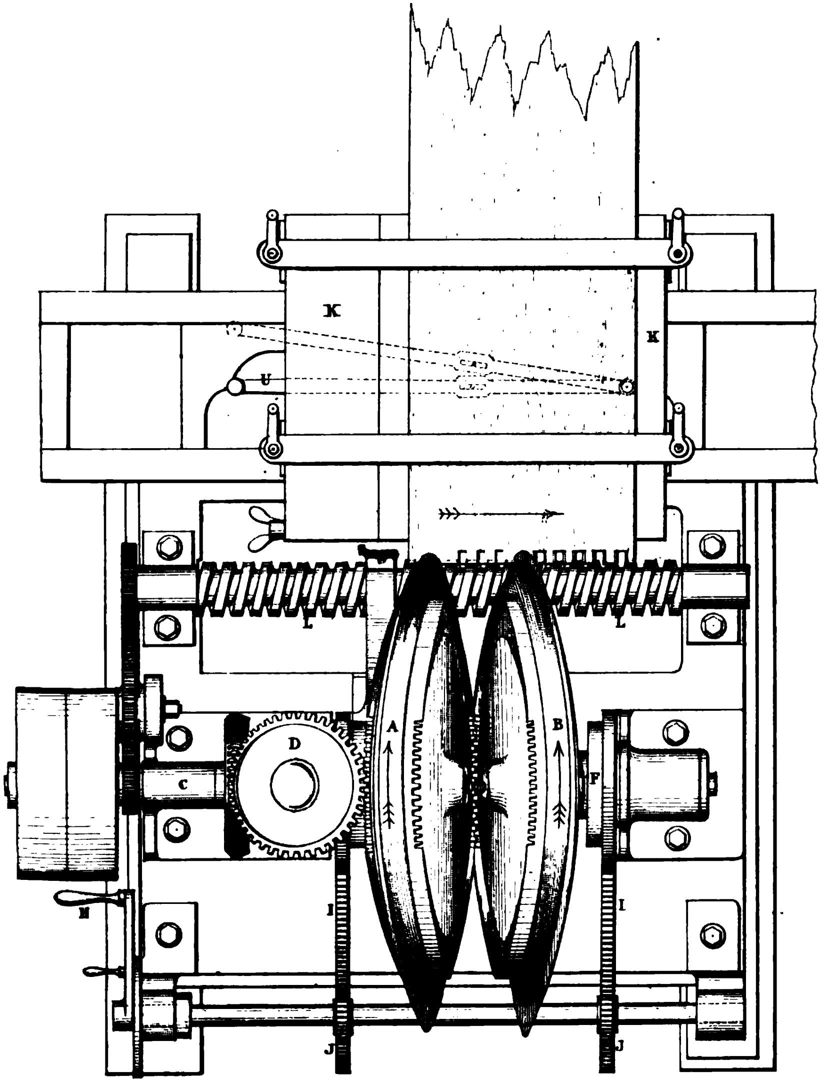
(Proceedings Inst. M E. 1868.)

Scale 1/10 th

DOVETAILING MACHINE.

Plate 23.

Fig 3. *Plan.*



(Proceedings Inst. M E. 1868.)

Scale 1/10th

0 5 10 15 20 25 30 *Inches.*

Detail of Circular Saws

Fig. 4. Side Elevation.

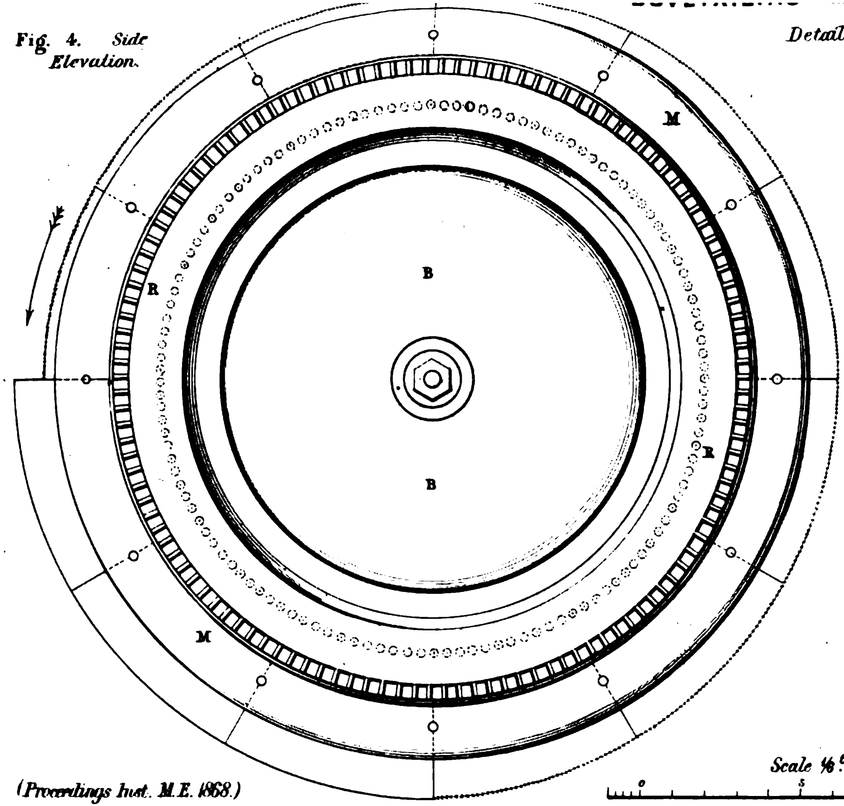
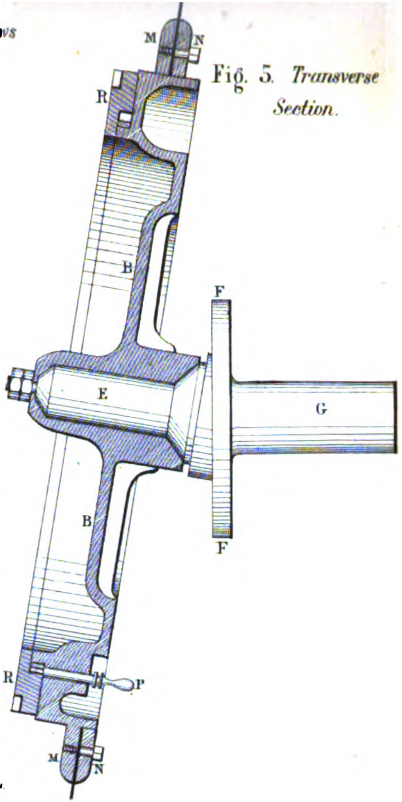


Fig. 5. Transverse Section.



Scale 1/8th

0 5 10 Inches

(Proceedings Inst. M.E. 1868.)

DOVETAILING MACHINE.

Ordinary dovetails.

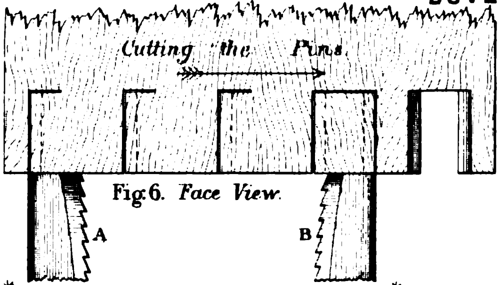


Fig 6. Face View.

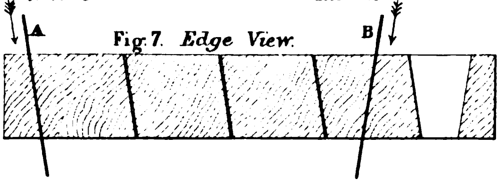


Fig 7. Edge View.

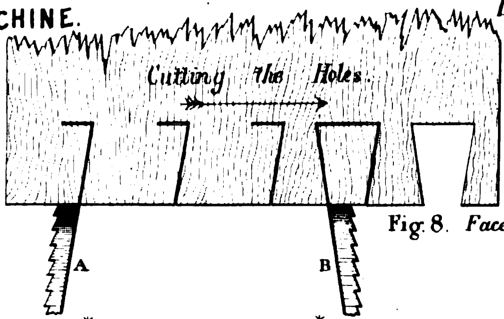


Fig 8. Face View.

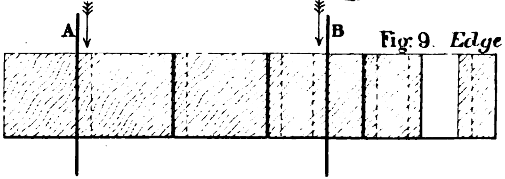


Fig 9. Edge View.

Concealed dovetails for mitre joints.

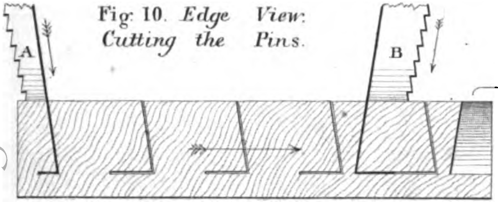


Fig 10. Edge View: Cutting the Pins.

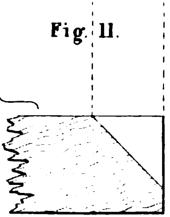


Fig 11.

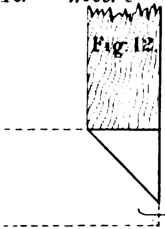


Fig 12.

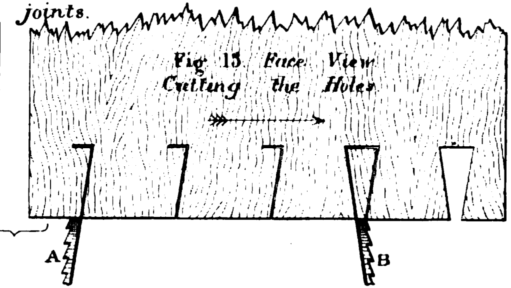


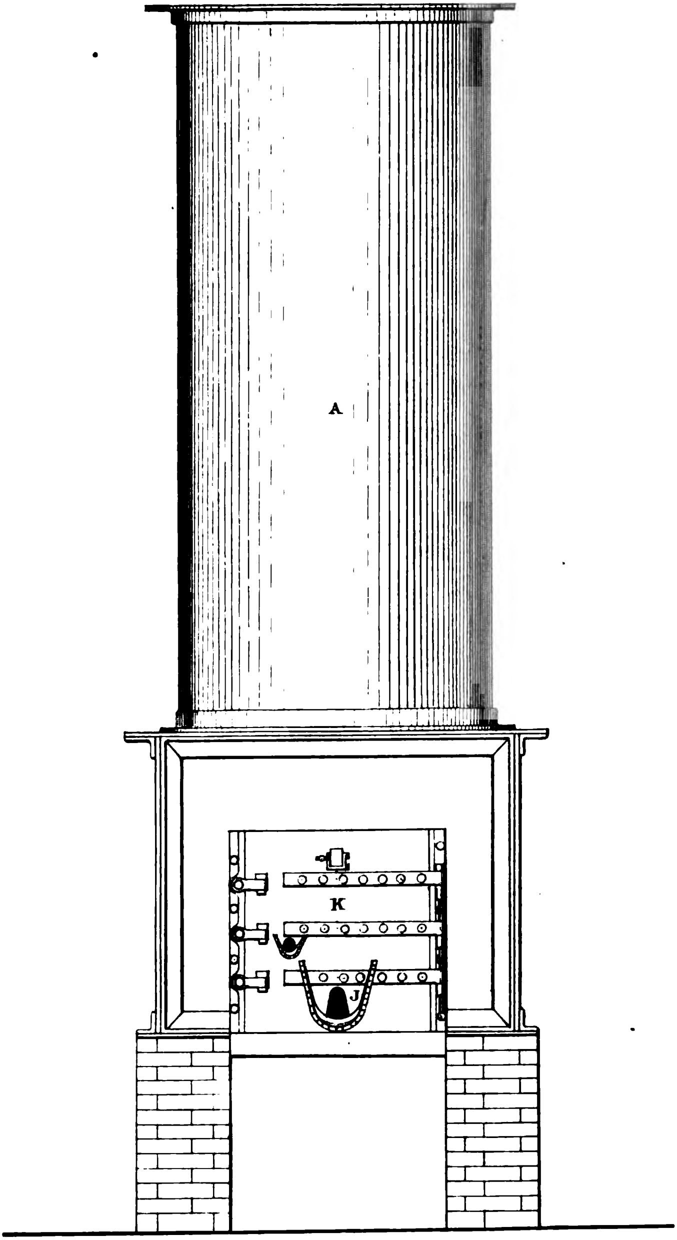
Fig 13. Face View Cutting the Holes.

(Proceedings Inst. M. E. 1868.)

Scale half full size.

FOUNDRY CUPOLA.

Fig. 1. *Front Elevation.*



(Proceedings Inst. M.E. 1868.)

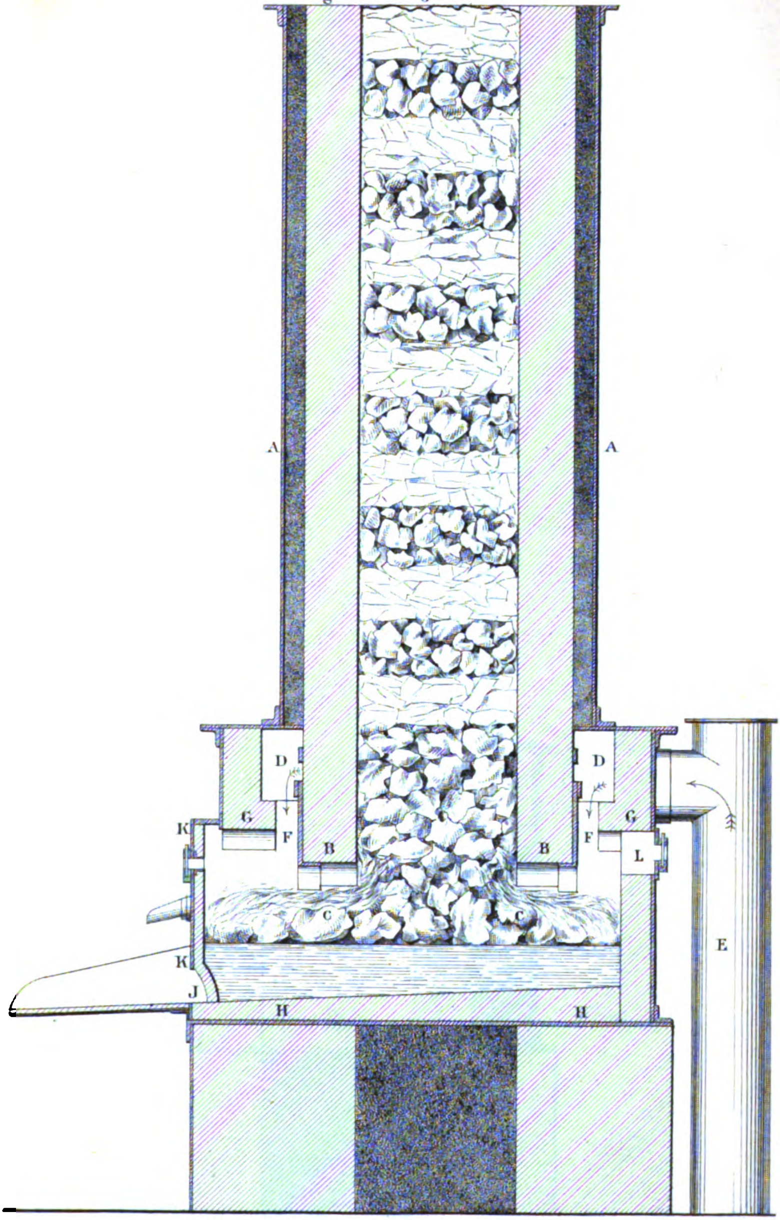
Scale 1/30th

10 5 0 10 20 30 40 50 60 70 80 90 100 *Inches.*

FOUNDRY CUPOLA.

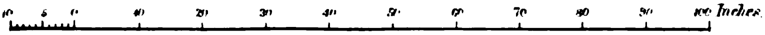
Plate 27.

Fig. 2. *Longitudinal Section.*



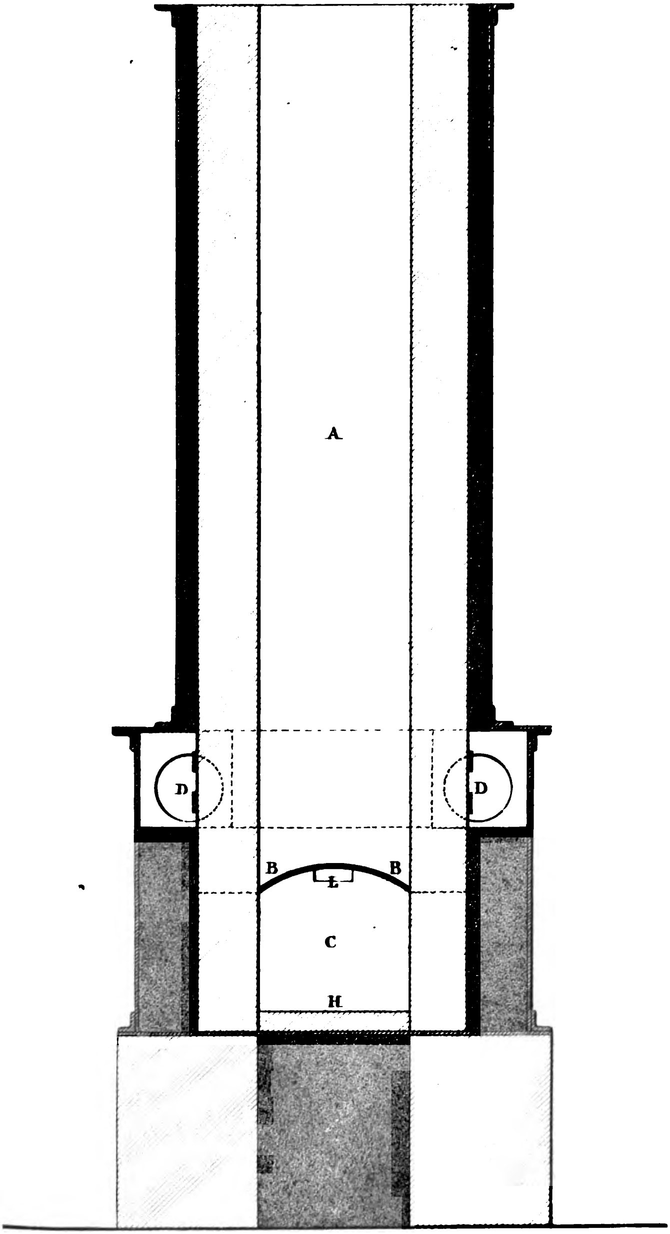
(Proceedings Inst. M.E. 1868.)

Scale $^1/_{30}$th.



FOUNDRY CUPOLA.

Fig. 3. *Transverse Section.*



(Proceedings Inst. M.E. 1868.)

Scale 1/30th

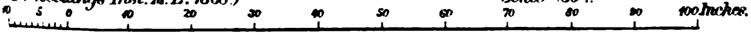


Fig. 4. *Sectional Plan through Shaft and through Air Chambers.*

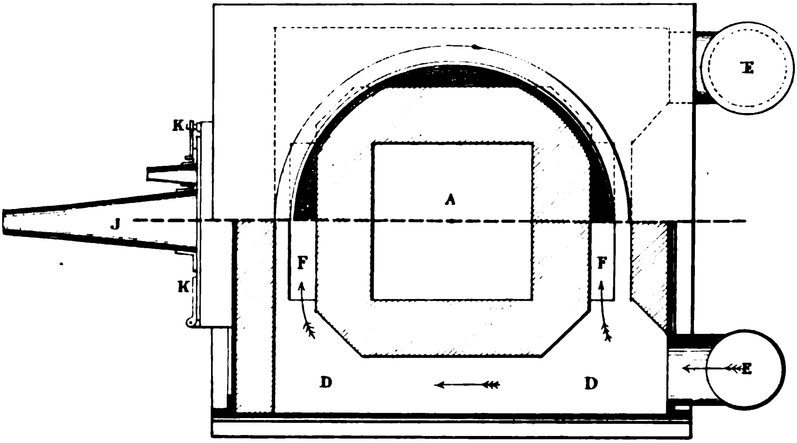
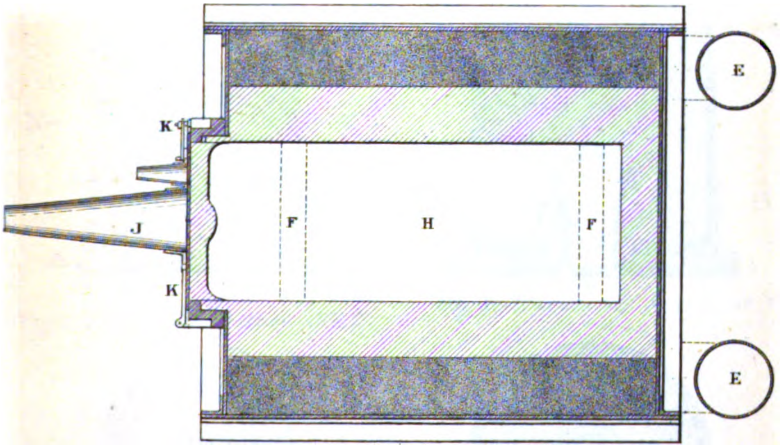
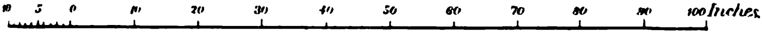


Fig. 5. *Sectional Plan at level of Hearth.*



(Proceedings Inst. M.E. 1868.) *Scale 1/30th*



FOUNDRY CUPOLA.

Plate 29.

Fig. 4. *Sectional Plan through Shaft and through Air Chambers.*

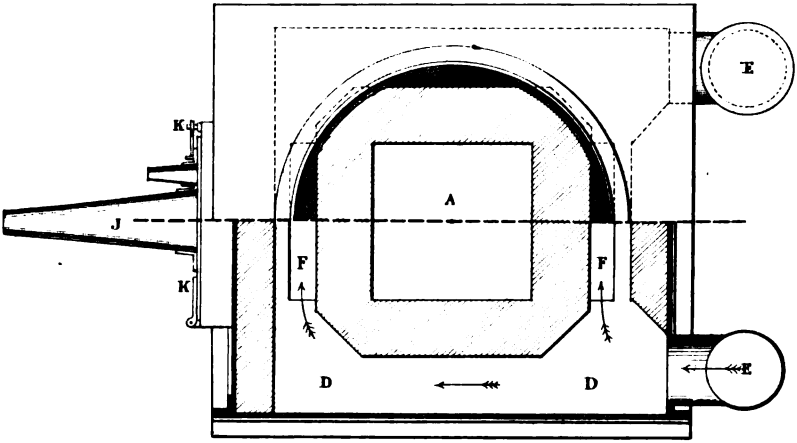
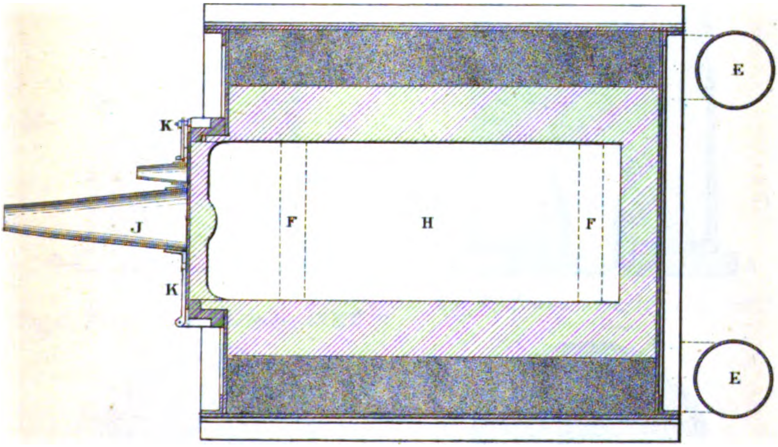


Fig. 5. *Sectional Plan at level of Hearth.*



(Proceedings Inst. M.E. 1868.) *Scale 1/30th*

10 5 0 10 20 30 40 50 60 70 80 90 100 *Inches.*

CARTRIDGE MACHINERY.

Plate 30.

Fig. 1. *Section of Spencer Cartridge. Rim-Fire.*

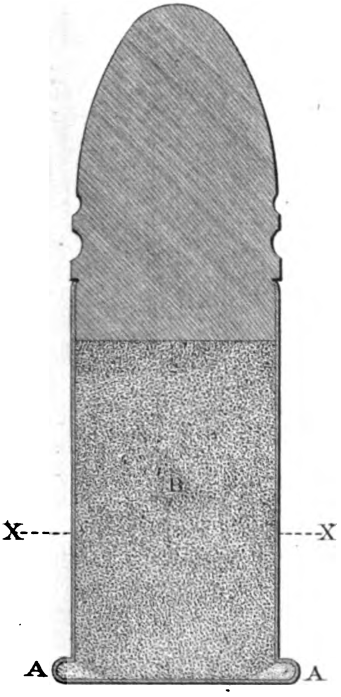


Fig. 2. *Transverse Section at* XX

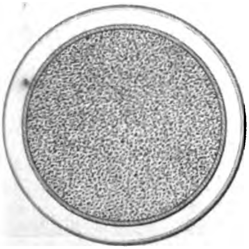


Fig. 3. *Section of Boxer Cartridge. Central-Fire.*

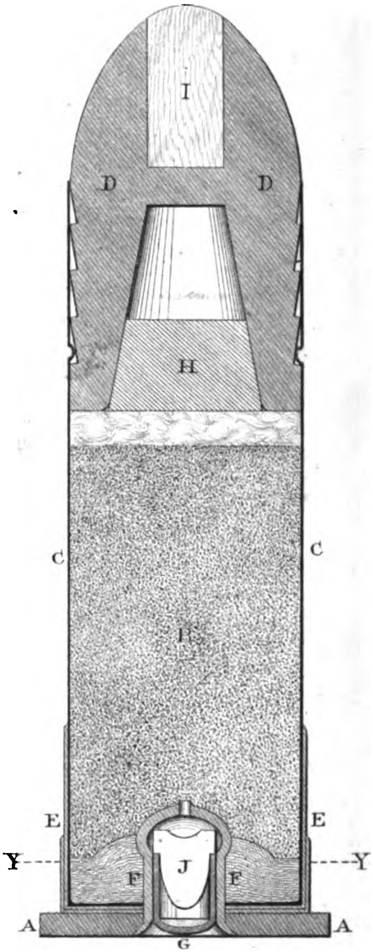
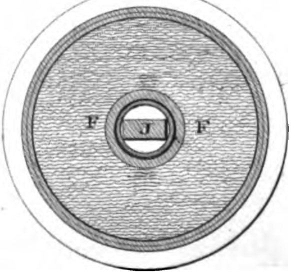


Fig. 4. *Transverse Section at* YY.



(Proceedings Inst. M. E. 1868.)

Scale double full size.

CARTRIDGE MACHINERY.

Fig. 5. Bullet - Making Machine. First operation.

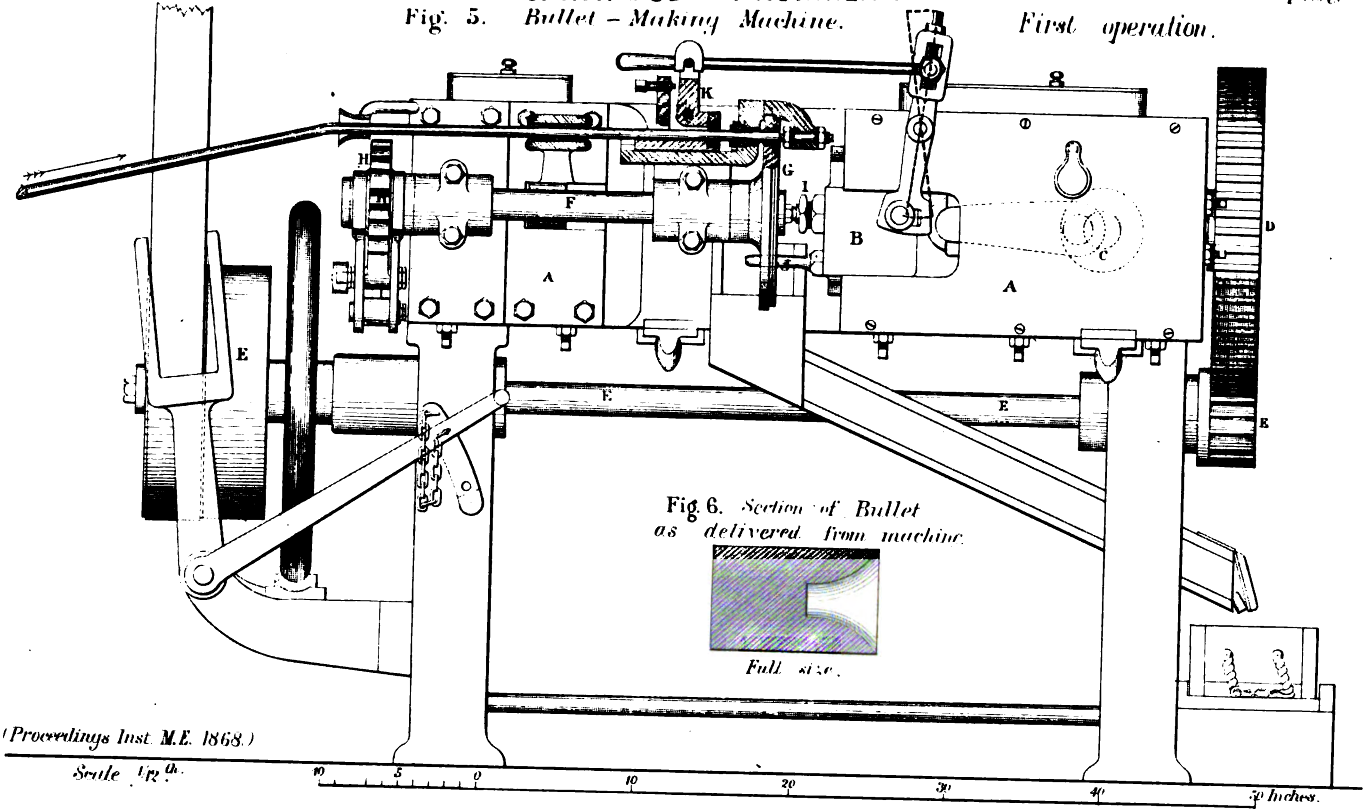


Fig. 6. Section of Bullet as delivered from machine.

Full size.

(Proceedings Inst. M.E. 1868.)

CARTRIDGE MACHINERY.

Fig. 7. *Bullet-Making Machine. Second operation.*

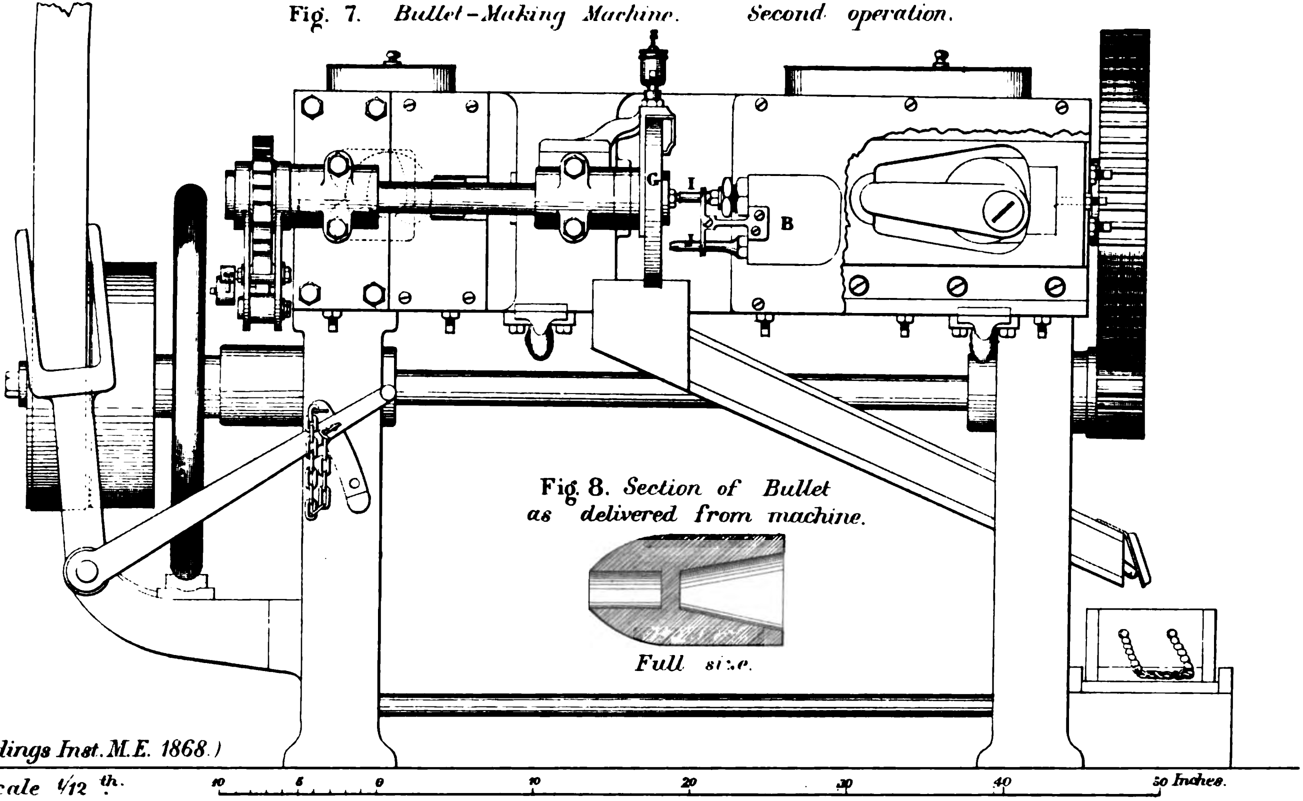


Fig. 8. *Section of Bullet as delivered from machine.*

Full size.

(Proceedings Inst. M.E. 1868.)

CARTRIDGE MACHINERY.

Bullet Making Machine. Second operation.

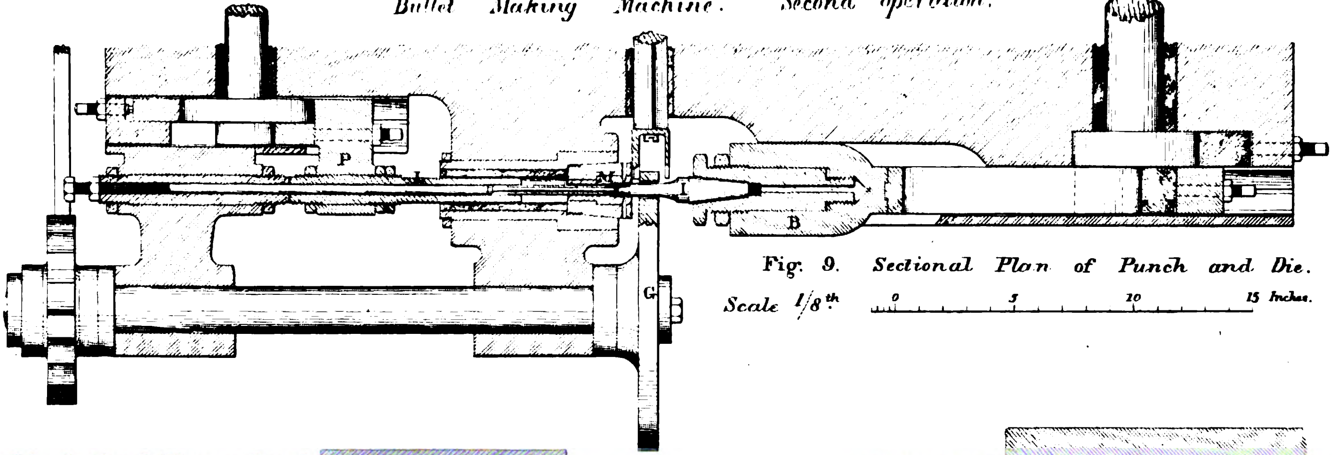


Fig. 9. *Sectional Plan of Punch and Die.*

Scale 1/8th.

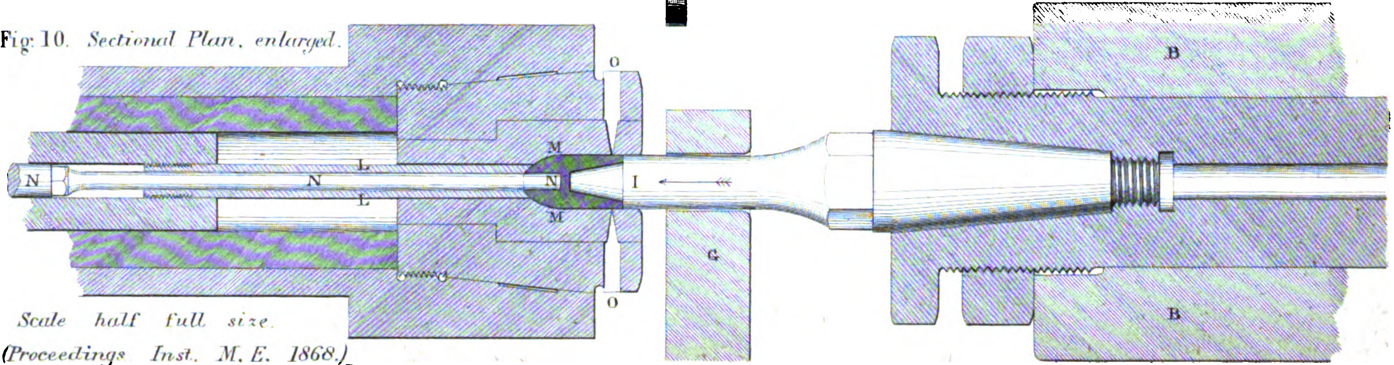
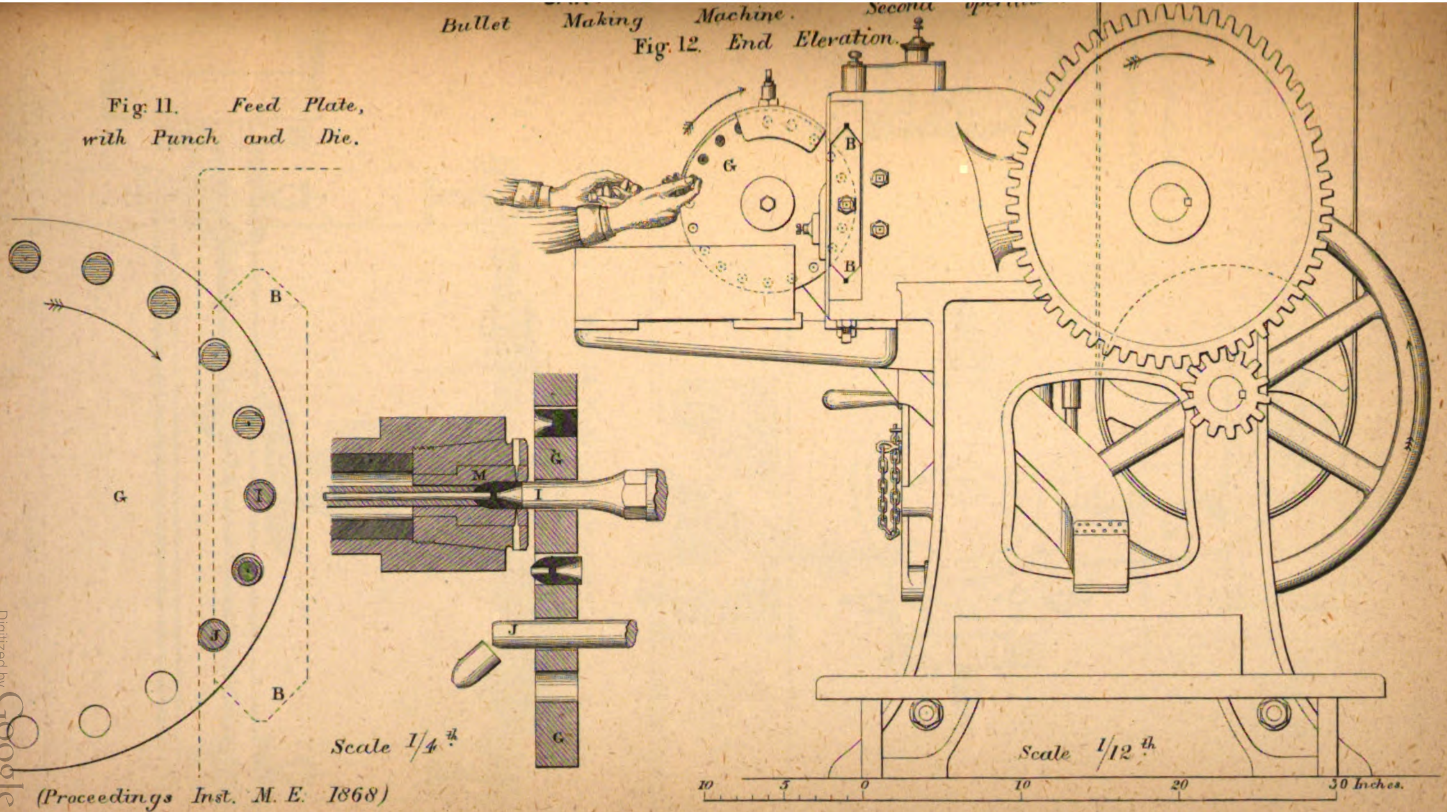


Fig. 10. *Sectional Plan, enlarged.*

Scale half full size.

(Proceedings Inst. M. E. 1868.)



Bullet Making Machine. Second

Fig: 11. Feed Plate, with Punch and Die.

Scale 1/4th.

Fig: 12. End Elevation.

Scale 1/12th.

(Proceedings Inst. M. E. 1868)

CARTRIDGE MACHINERY. *Plate 35.*

Canneluring Machine.

Fig. 13.
Plan.

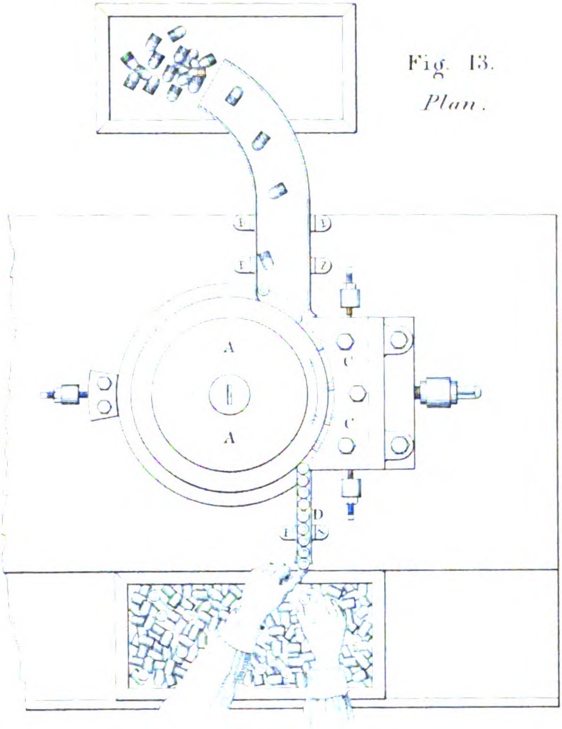
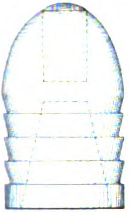
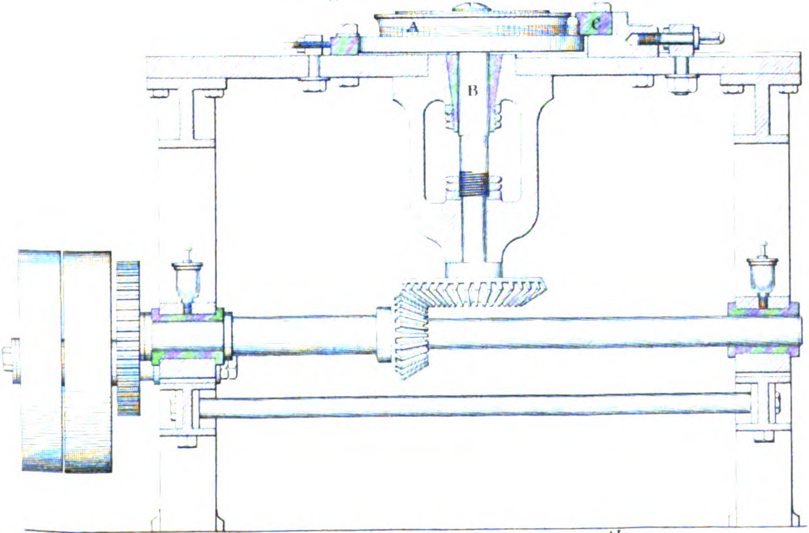


Fig. 15. *Bullet after passing thro' machine.*



Full size.

Fig. 14. *Vertical Section.*



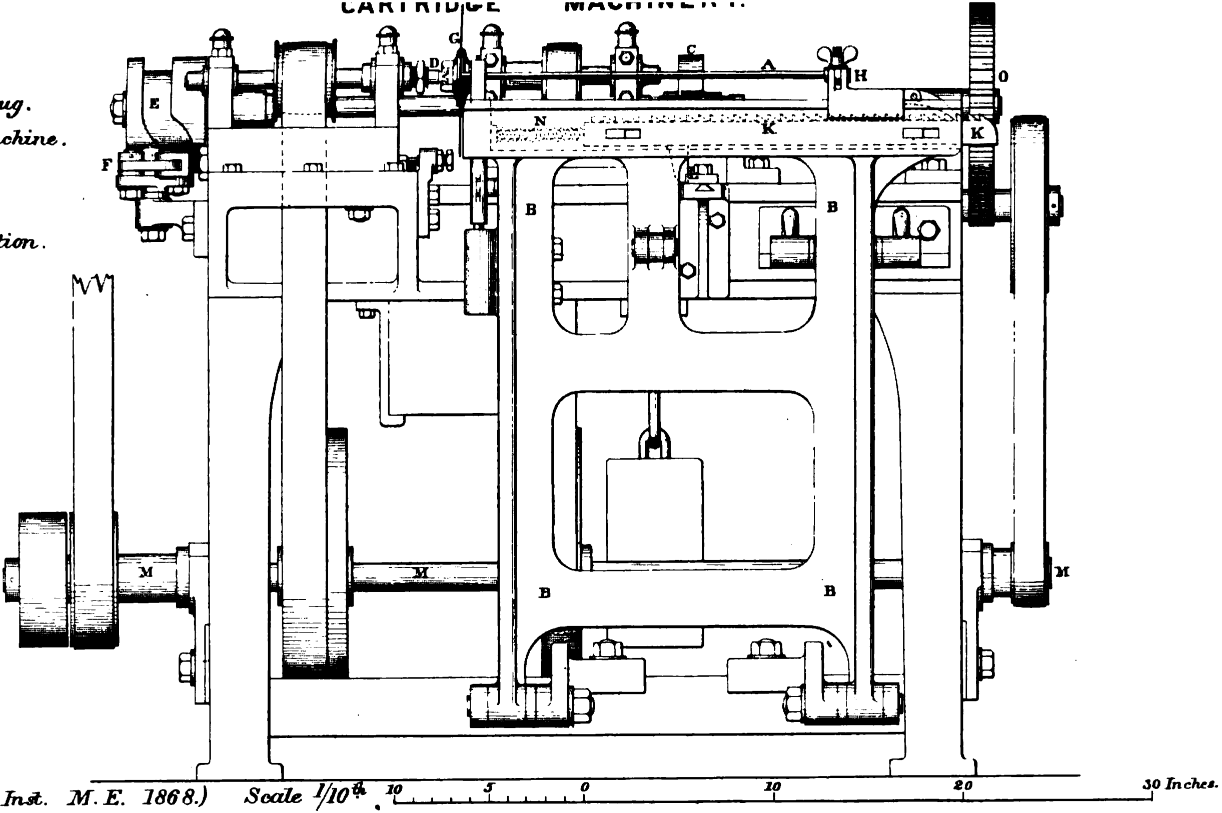
(Proceedings Inst. M.E. 1868.)

Scale 1/12th

10 5 0 10 20 30 Inches.

Wood Plug.
Making Machine.

Fig. 16.
Front Elevation.



(Proceedings Inst. M.E. 1868.) Scale 1/10th.

CARTRIDGE MACHINERY.

Wood Plug Making Machine.

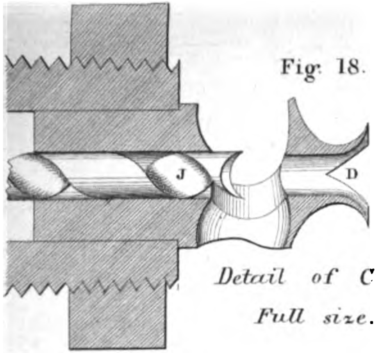


Fig: 18.

Detail of Cutter. Full size.

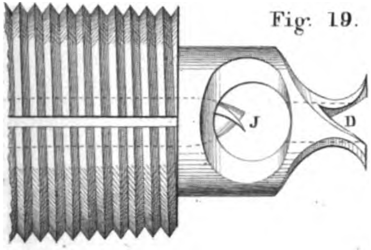


Fig: 19.

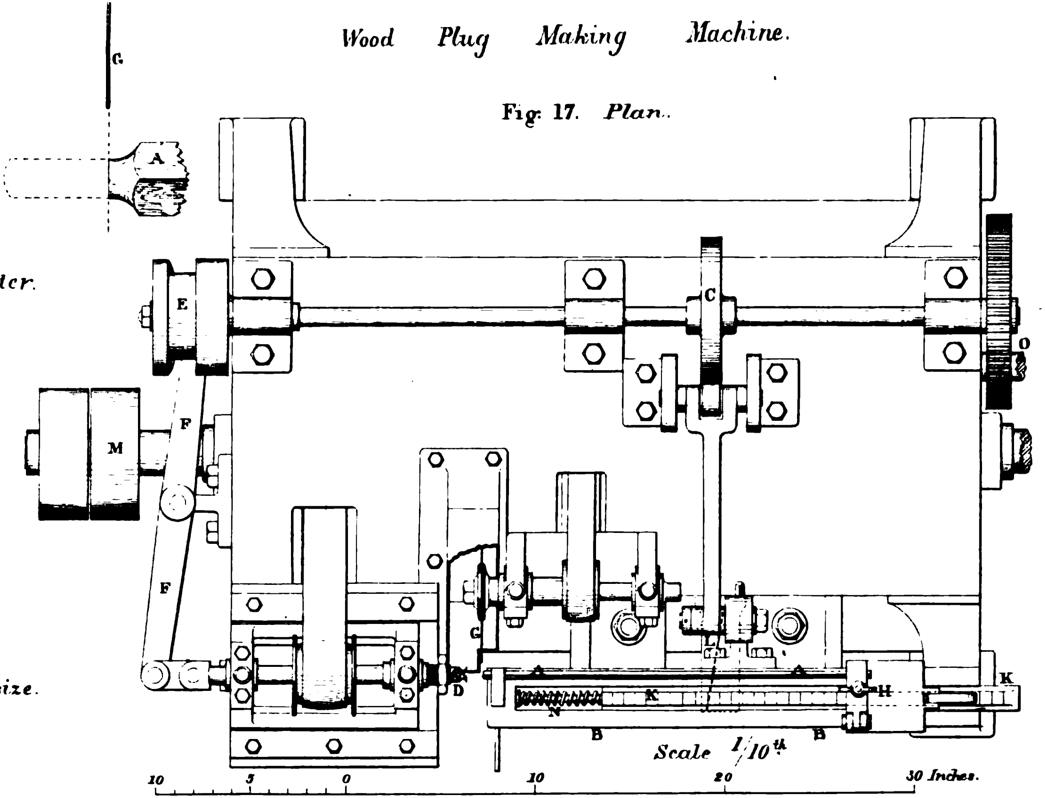


Fig: 17. *Plan.*

Scale 1/10th

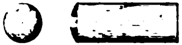


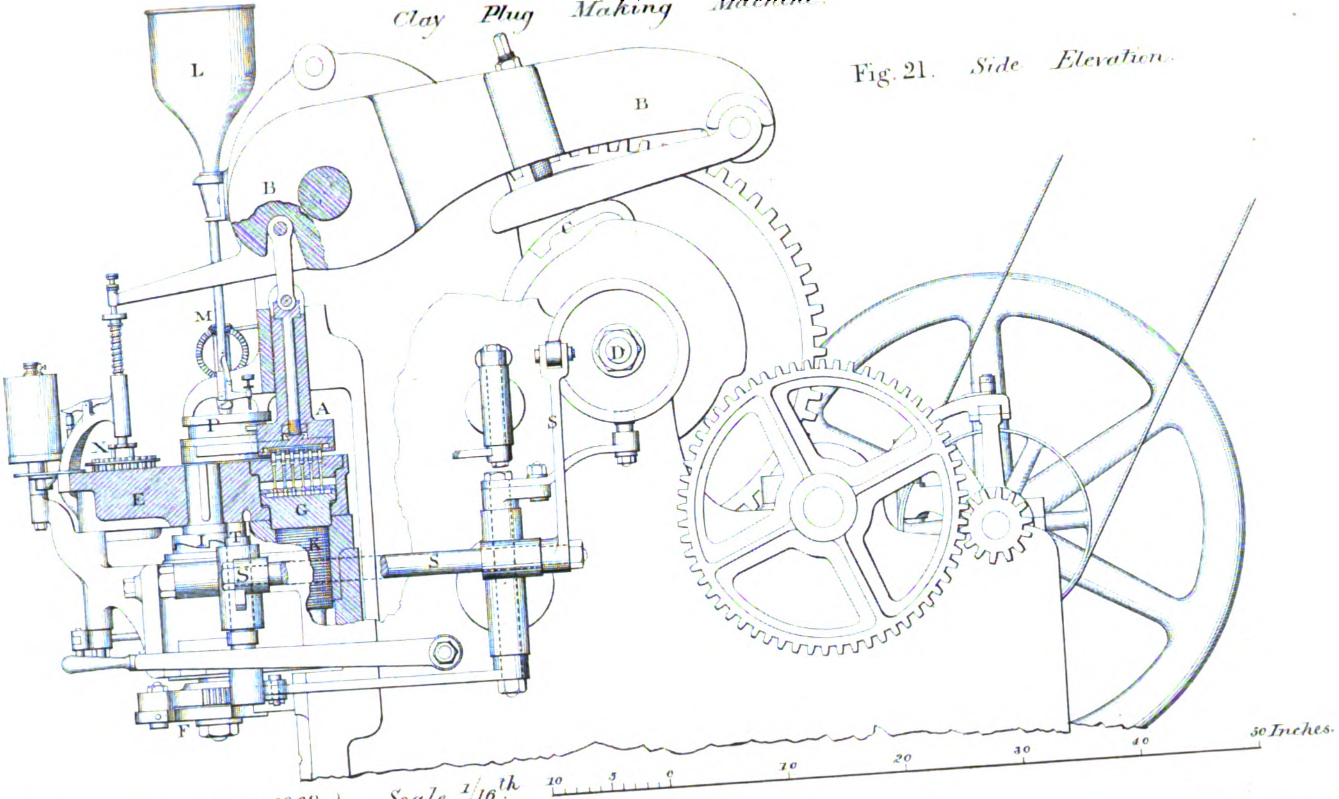
Fig: 20. *Wood Plug. Full size.*

(Proceedings Inst. M. E. 1868)

CARTRIDGE MACHINERY.

Clay Plug Making Machine.

Fig. 21. *Side Elevation.*



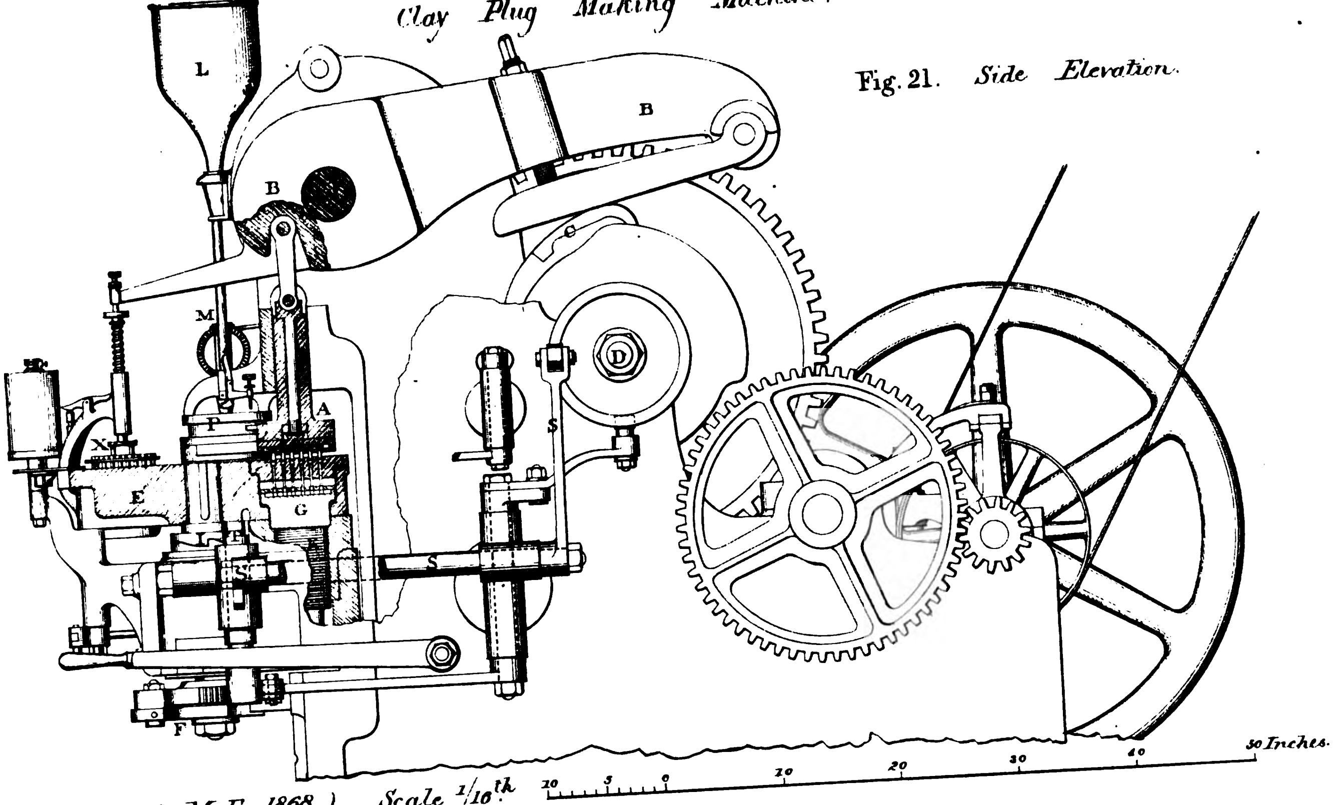
Scale 1/16th

(Proceedings Inst. M. E. 1868.)

CARTRIDGE MACHINERY.

Clay Plug Making Machine.

Fig. 21. *Side Elevation.*



Scale 1/10th.

(Proceedings Inst. M. E. 1868.)

Plate 39.

CARTRIDGE MACHINERY.

Clay Plug Making Machine.

Fig. 22.

Plan of Ratchet Wheel turning the Moulding Table, (looking upwards.)

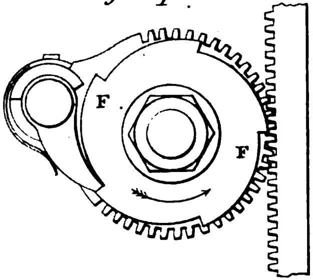
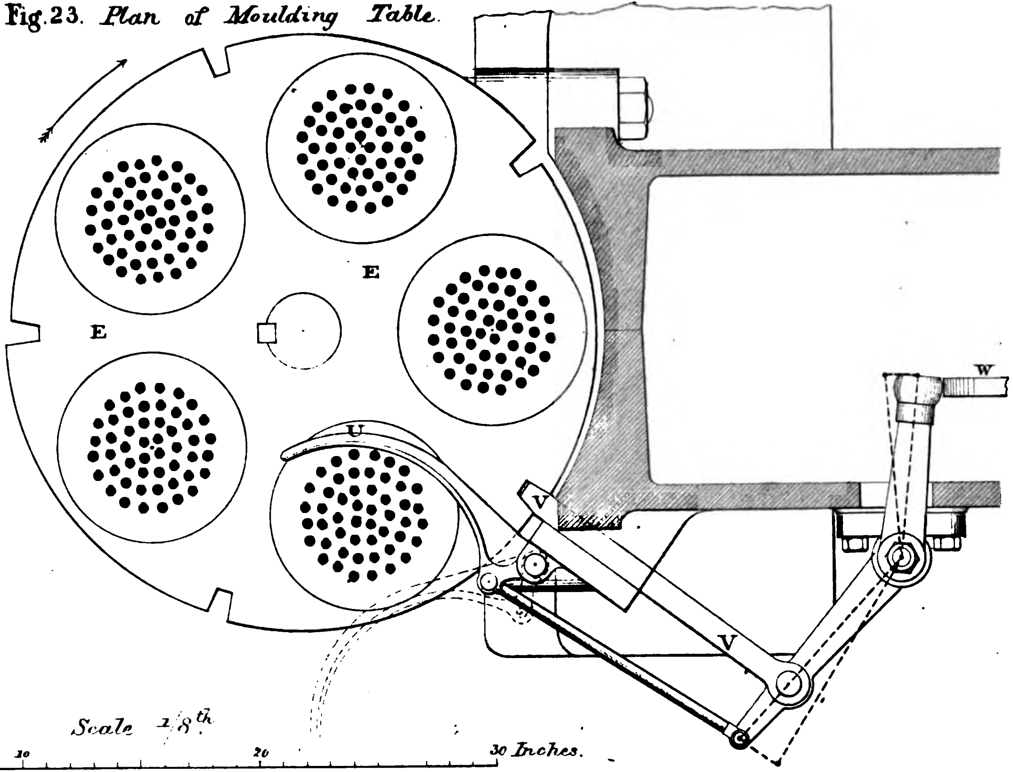


Fig. 23. Plan of Moulding Table.



(Proceedings Inst. M. E. 1868.)

Scale 1/8th

0 10 20 30 Inches.

CARTRIDGE MACHINERY.

Plate 40.

Clay Plug Making Machine.

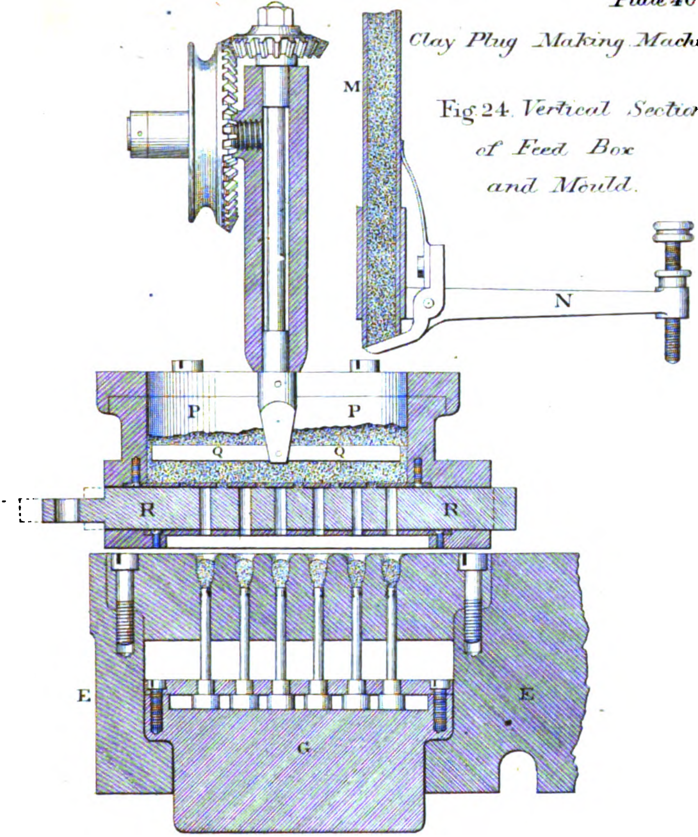


Fig. 24. Vertical Section of Feed Box and Mould.

Fig. 25. Vertical Section of Pressing Slide and Mould.

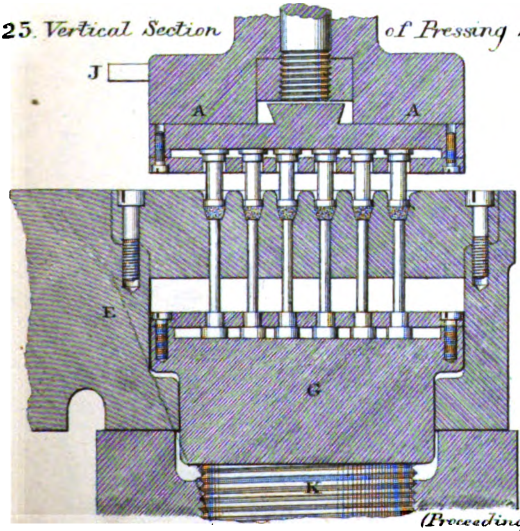
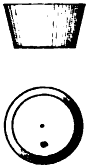


Fig. 26. Clay Plug.



Full size.

(Proceedings Inst. M.E. 1868.)

Scale 1/4th 0 1 2 3 4 5 6 7 8 9 10 Inches.

CARTRIDGE MACHINERY.

Machine for Warming and Gauging the Bullet, and Pressing in the Clay Plug.

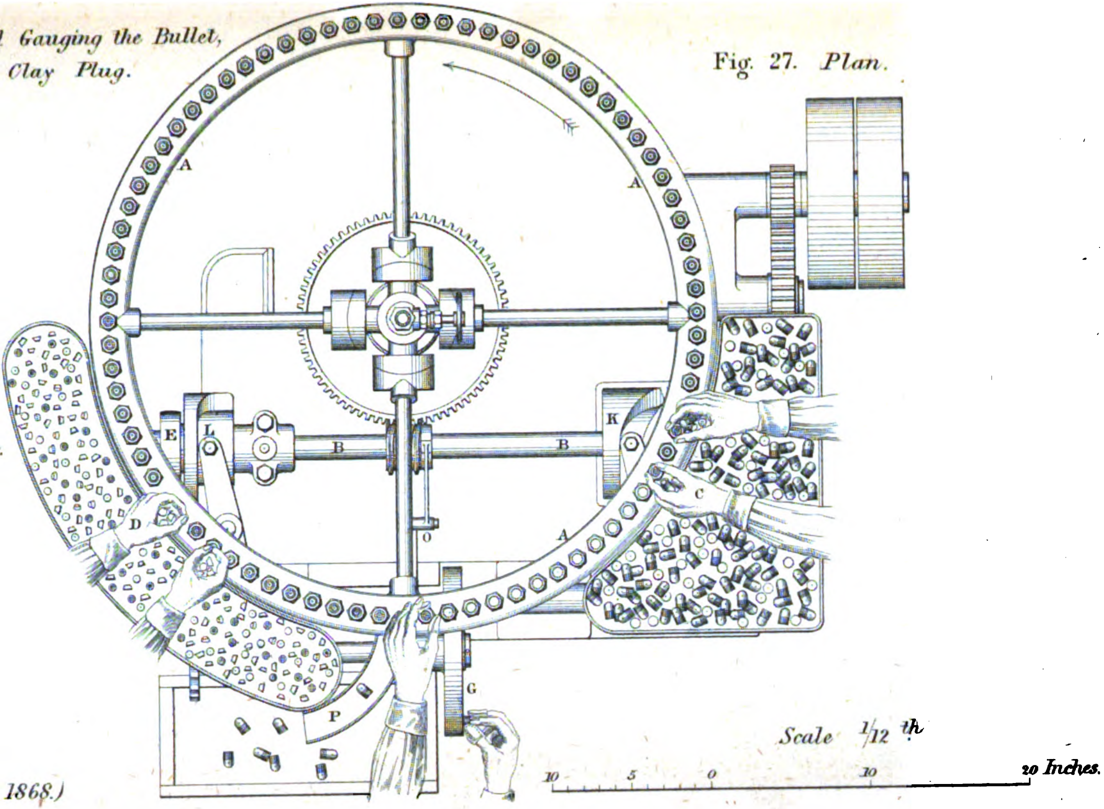
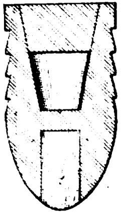


Fig. 27. *Plan.*

Fig. 28.

Section of Bullet as delivered from machine.



Full size.

(Proceedings Inst. M. E. 1868.)

CARTRIDGE MACHINERY. *Plate 42.*

Machine for Warming and Gauging the Bullet, and Pressing in the Clay Plug.

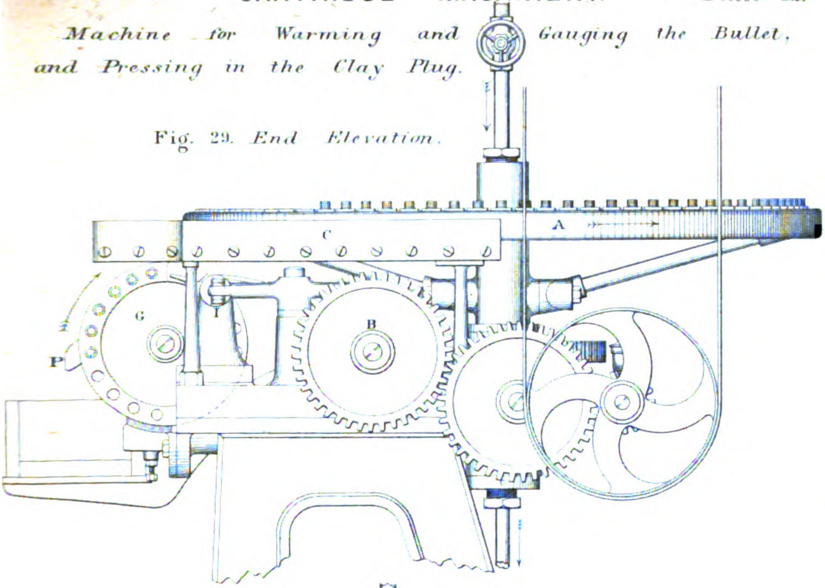


Fig. 29. *End Elevation.*

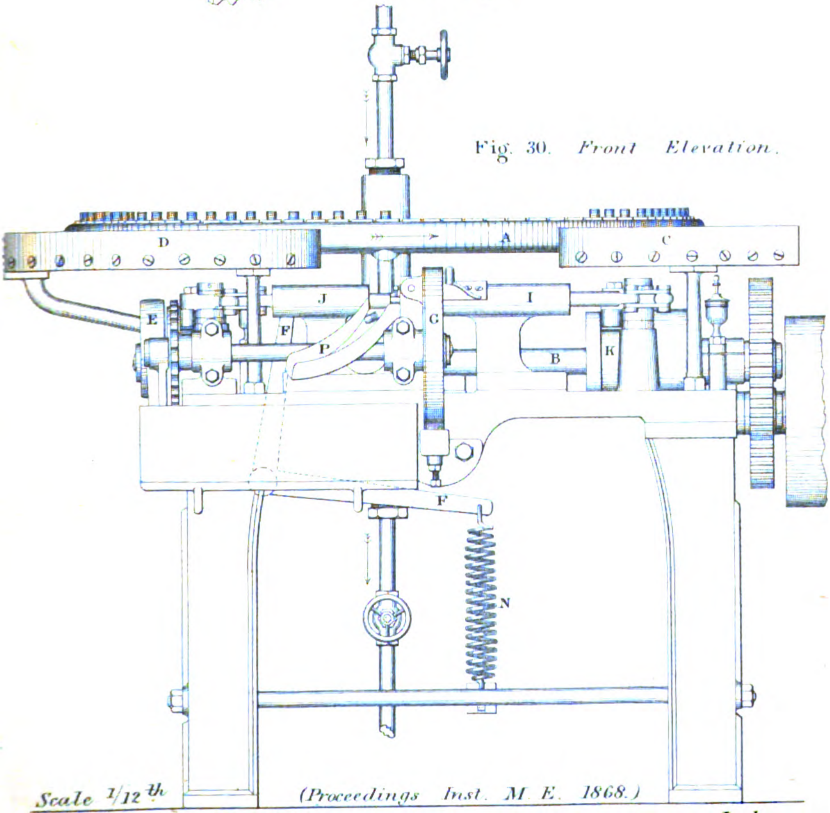


Fig. 30. *Front Elevation.*

Scale 1/12th

(Proceedings Inst. M. E. 1868.)

10 5 0 10 20 30 *Inches.*

CARTRIDGE MACHINERY.

Pressing in the Clay Plug, and Gauging the Bullet.

Fig. 31. *Bullet in the Feed Plate.*

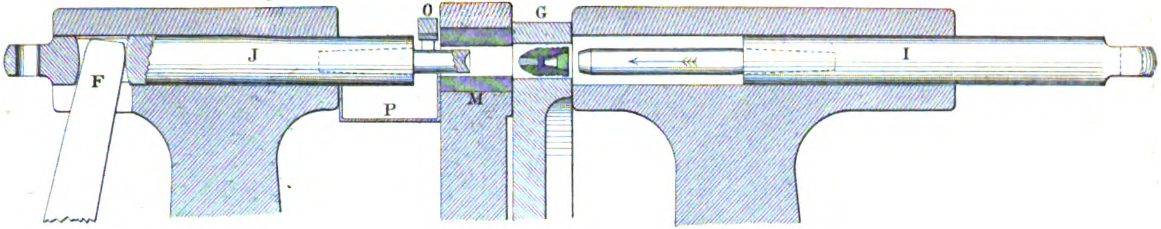


Fig. 32. *Bullet in the Gauge, and Clay Plug pressed in.*

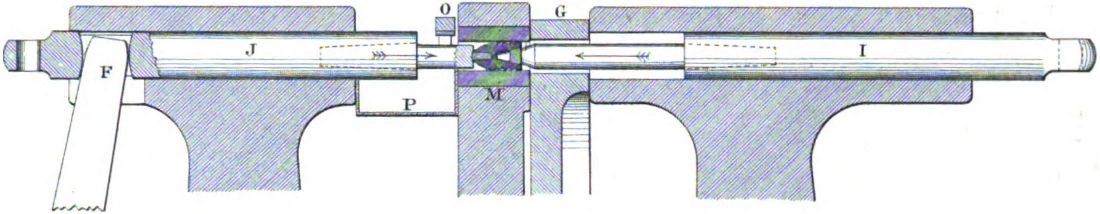
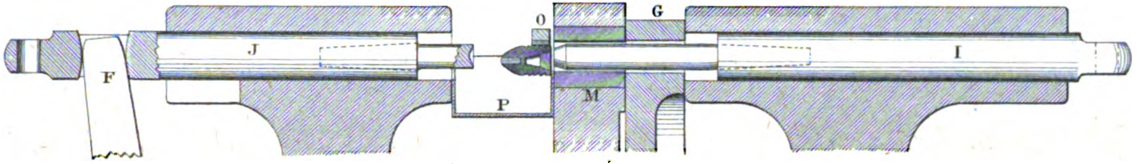


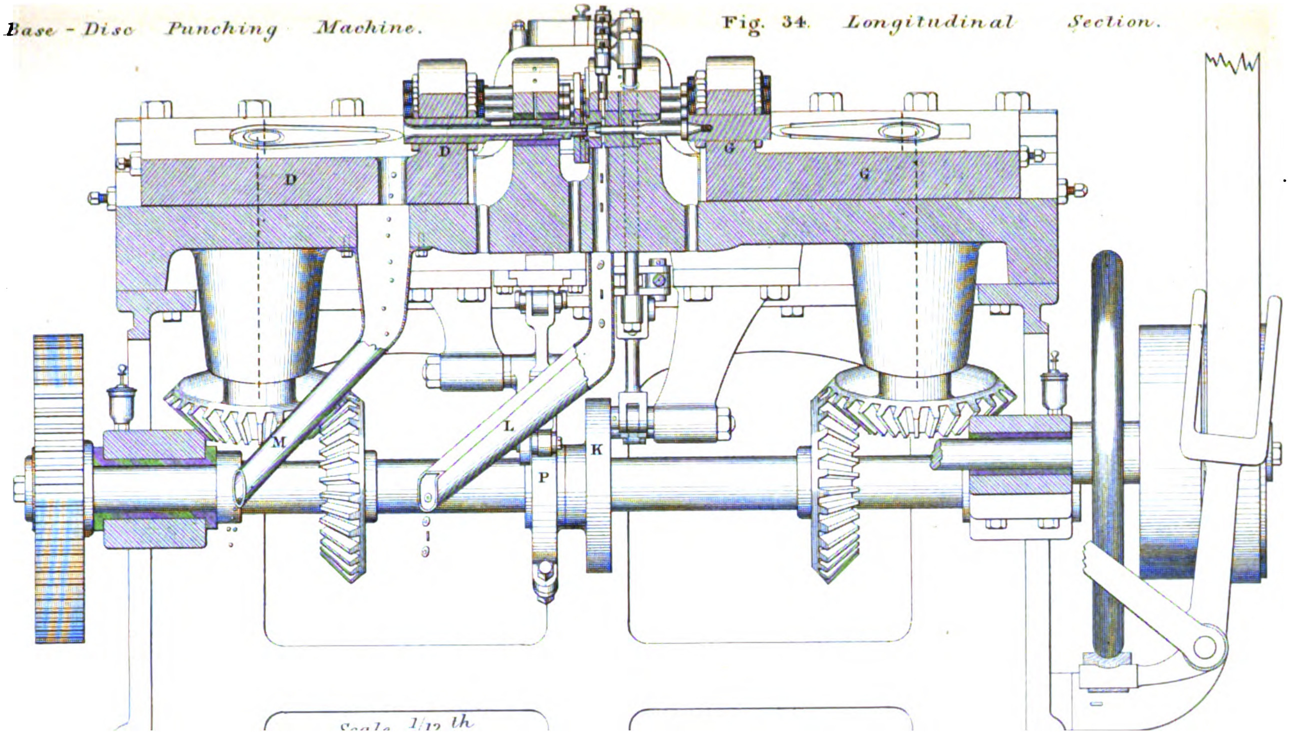
Fig. 33. *Bullet discharged from Gauge.*



(Proceedings Inst. M. E. 1868.) *Scale 1/4 th* 0 5 10 15 *Inches.*

CARTRIDGE MACHINERY.

Base - Disc Punching Machine. Fig. 34. Longitudinal Section.



Scale 1/12 th

CARTRIDGE MACHINERY.

Base - Disc Punching Machine.

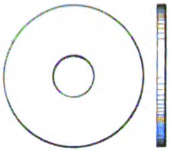


Fig. 37. *Base Disc, full size.*

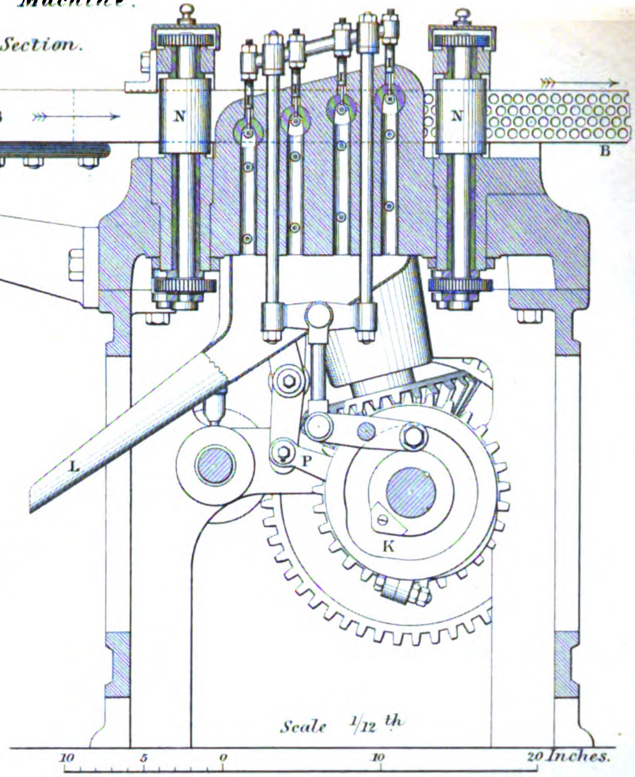


Fig. 35. *Transverse Section.*

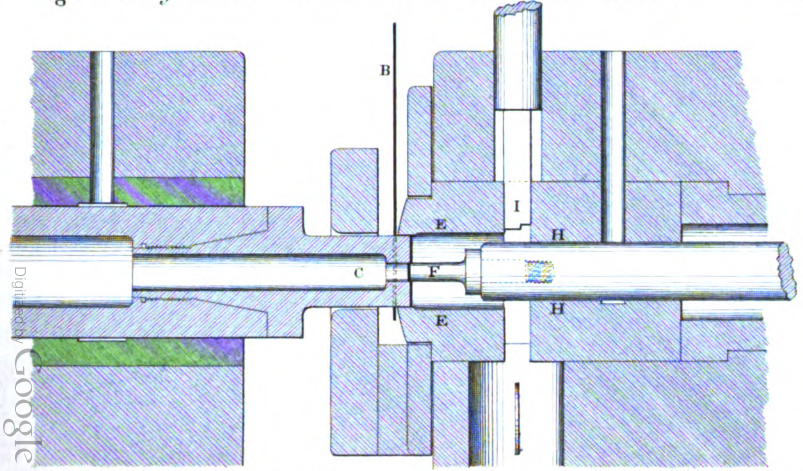


Fig. 36. *Longitudinal Section of Punch and Bolster.*

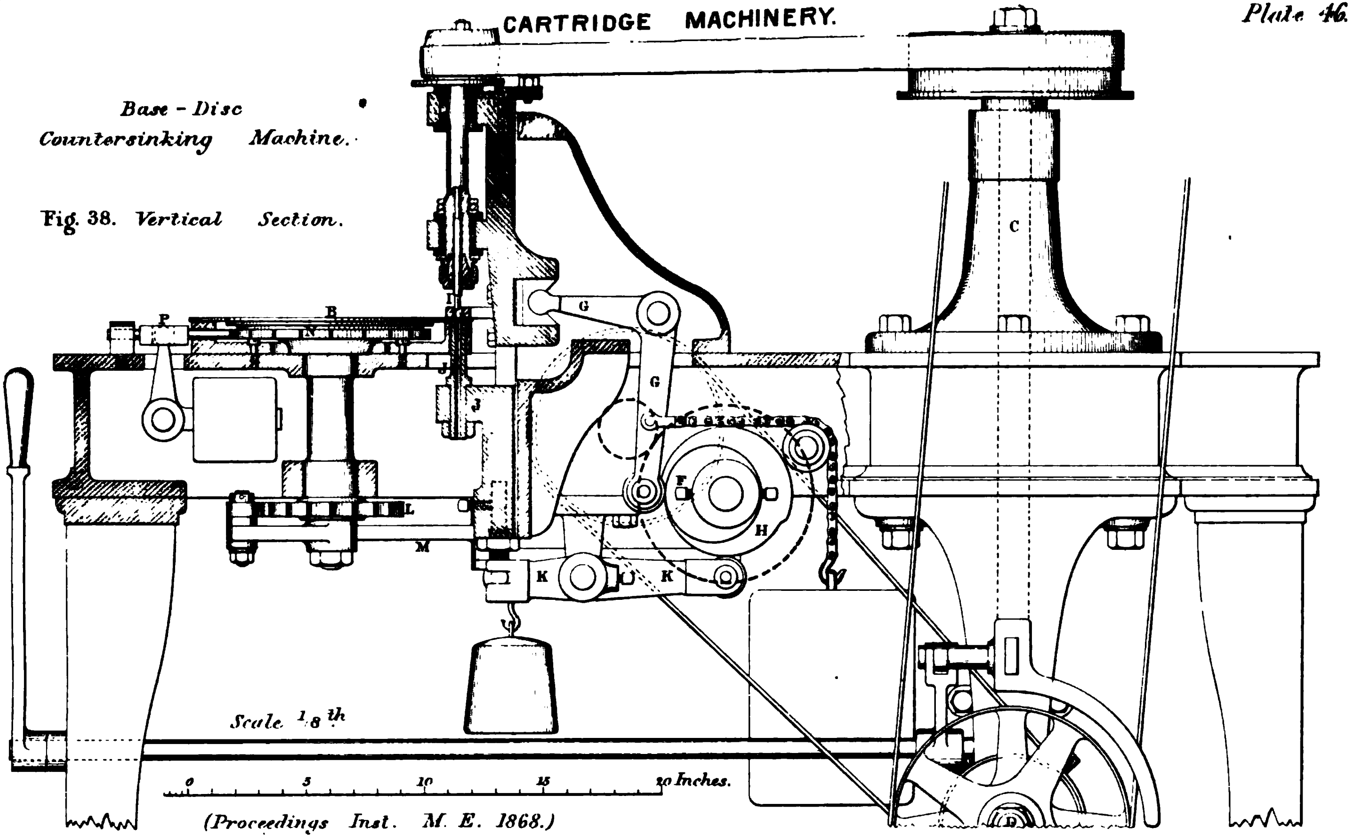
(Proceedings Inst. M. E. 1868.)

Scale half full size.

CARTRIDGE MACHINERY.

Base - Disc
Countersinking Machine.

Fig. 38. Vertical Section.



(Proceedings Inst. M. E. 1868.)

CARTRIDGE MACHINERY.

Base-Disc Countersinking Machine.

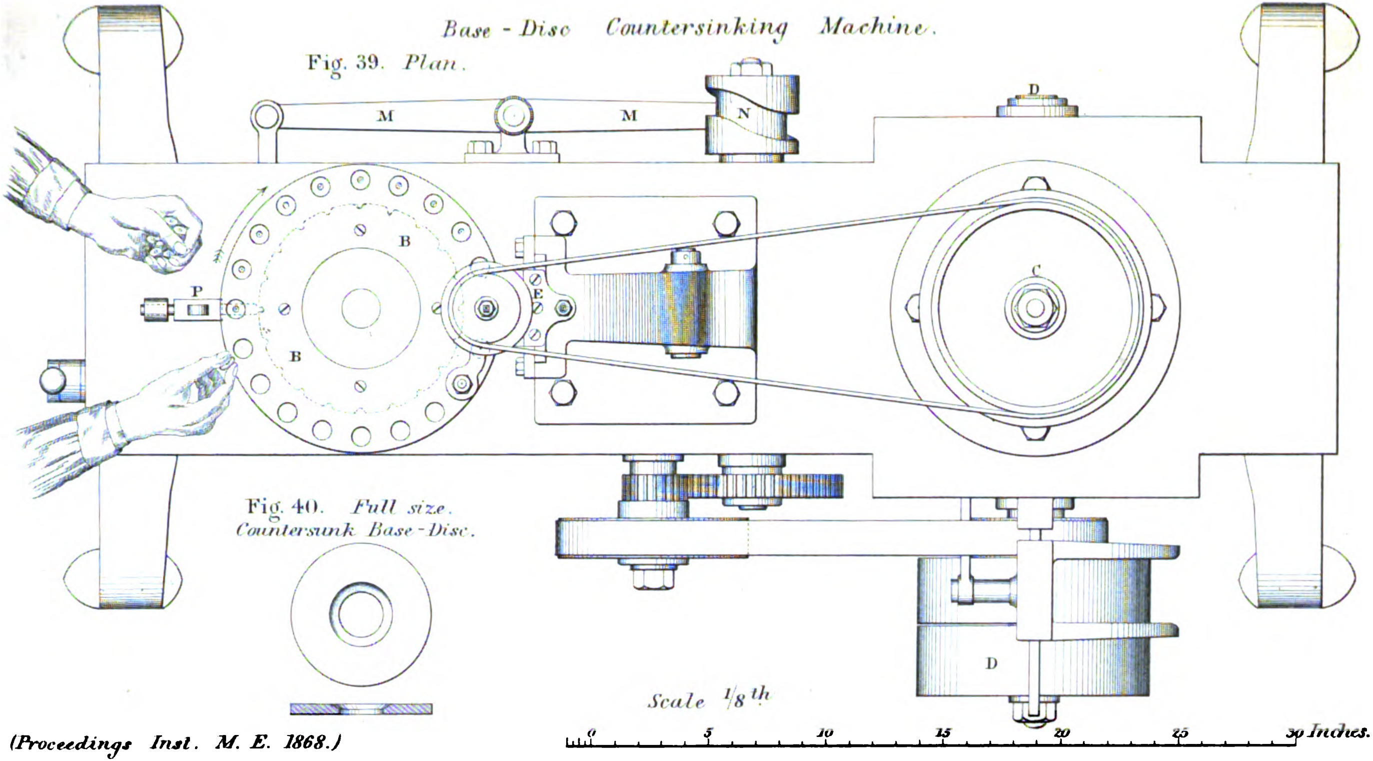


Fig. 39. *Plan.*

Fig. 40. *Full size.*
Countersunk Base-Disc.

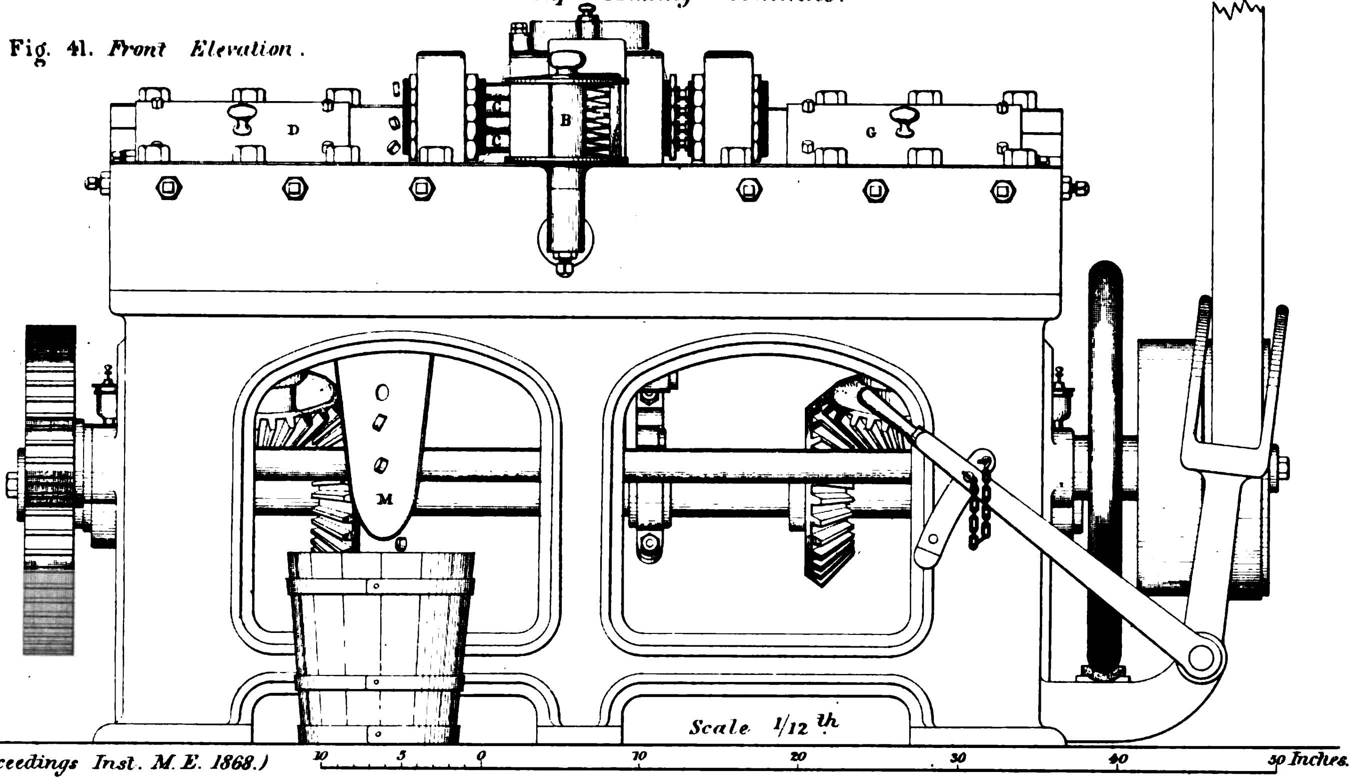
Scale 1/8th

(Proceedings Inst. M. E. 1868.)

CARTRIDGE MACHINERY.

Base - Cup Making Machine.

Fig. 41. *Front Elevation.*



(Proceedings Inst. M. E. 1868.)

CARTRIDGE MACHINERY.

Base-Cup Making Machine.

Fig. 42. *End Elevation.*

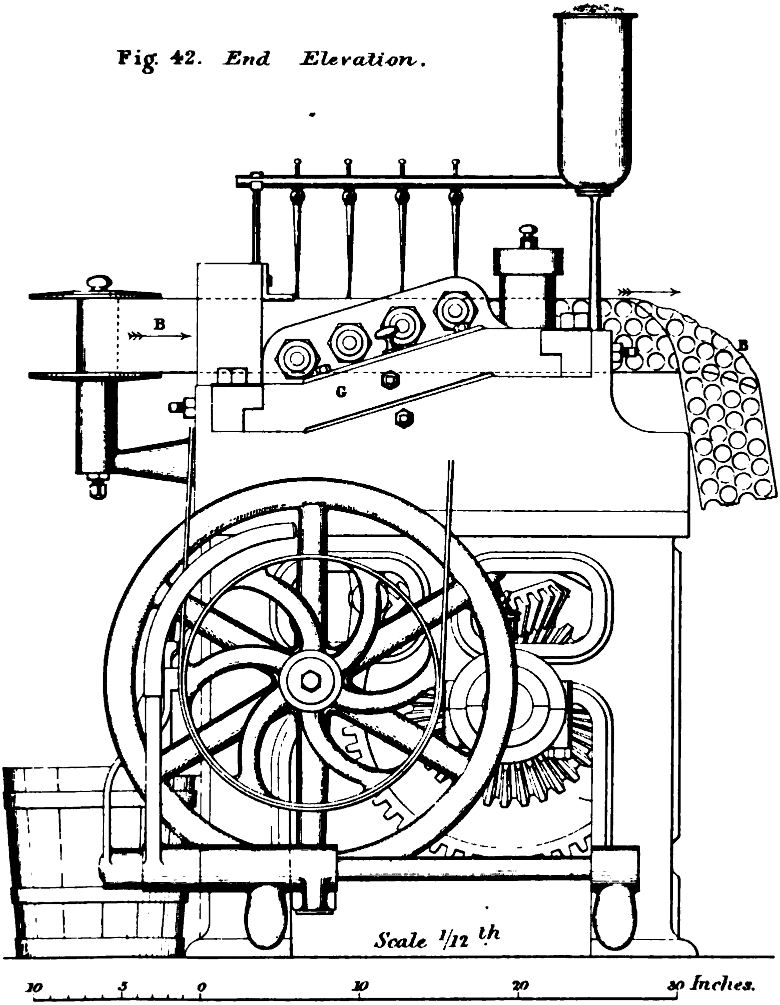
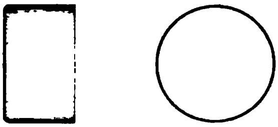


Fig. 43. *Deep Base-Cup, as delivered from machine.*



Full size.

(Proceedings Inst. M.E. 1868.)

CARTRIDGE MACHINERY.

Base-Cup Making Machine.

Fig. 44. *Longitudinal Section of Punches and Dies. Scale 1/12th.*

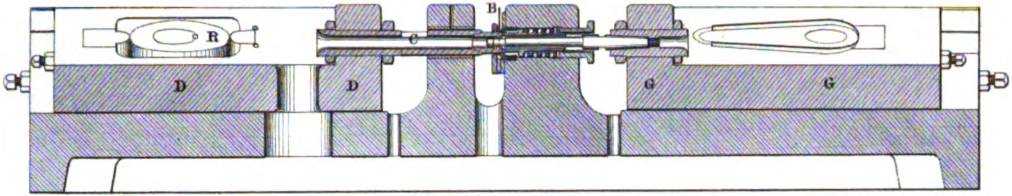
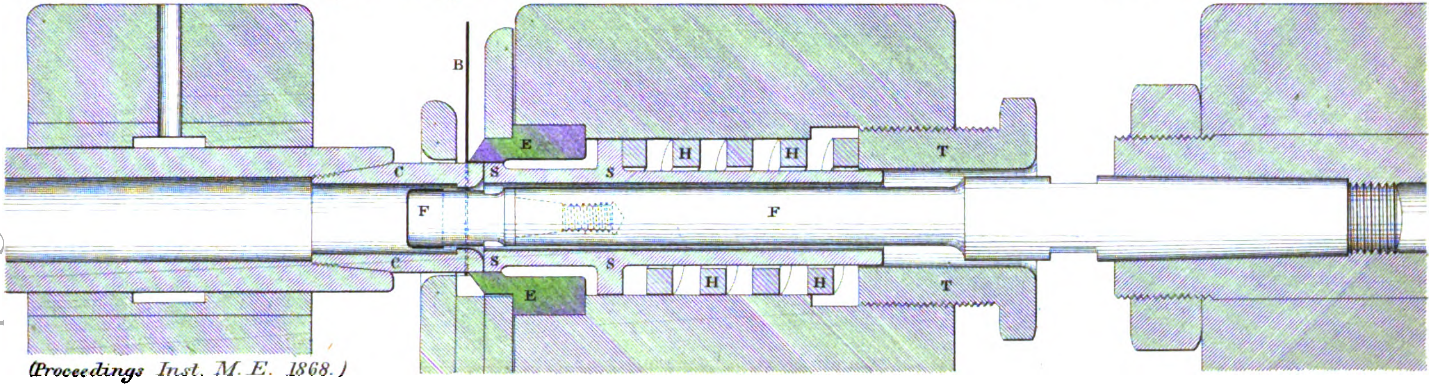


Fig. 45. *Enlarged Longitudinal Section of Punch and Bolster. Scale half full size.*



(Proceedings Inst. M.E. 1868.)

CARTRIDGE MACHINERY.

Hand Lever Press for punching Hole in Base Cups.

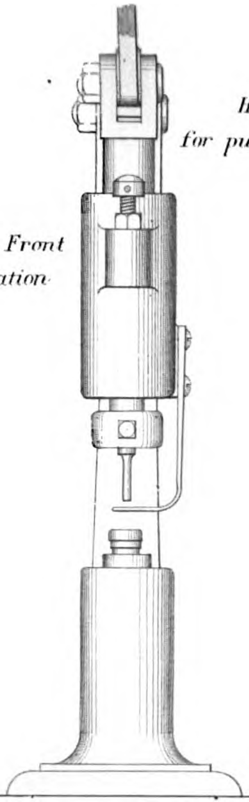


Fig. 46. *Front Elevation.*

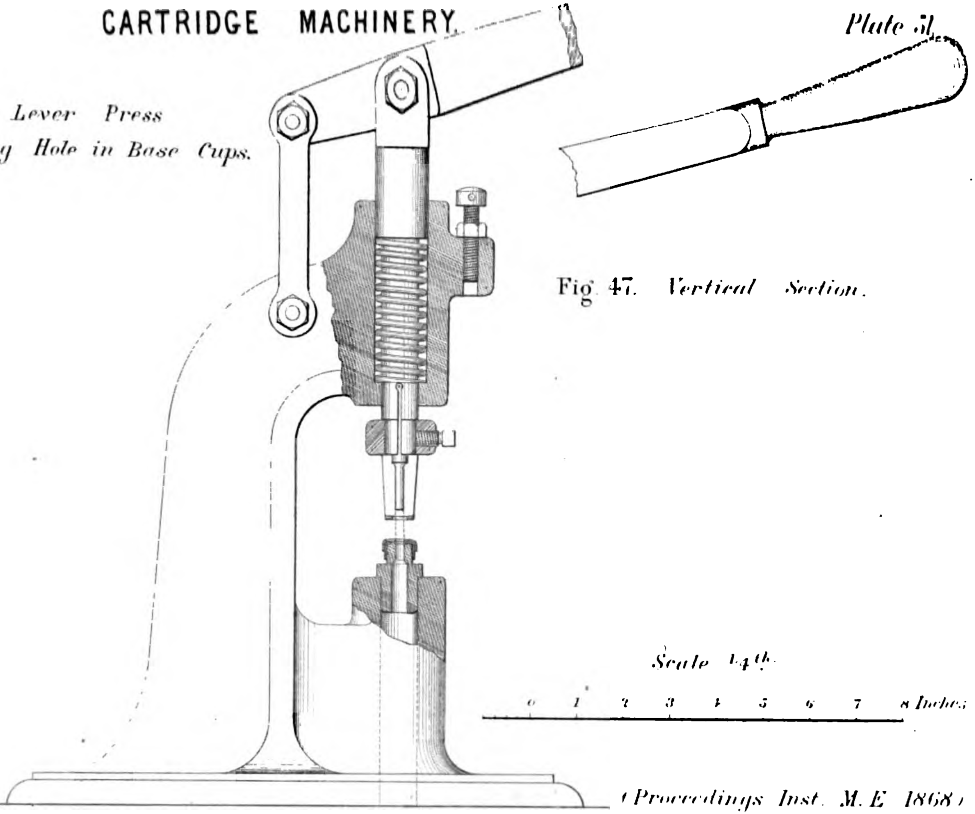


Fig. 47. *Vertical Section.*

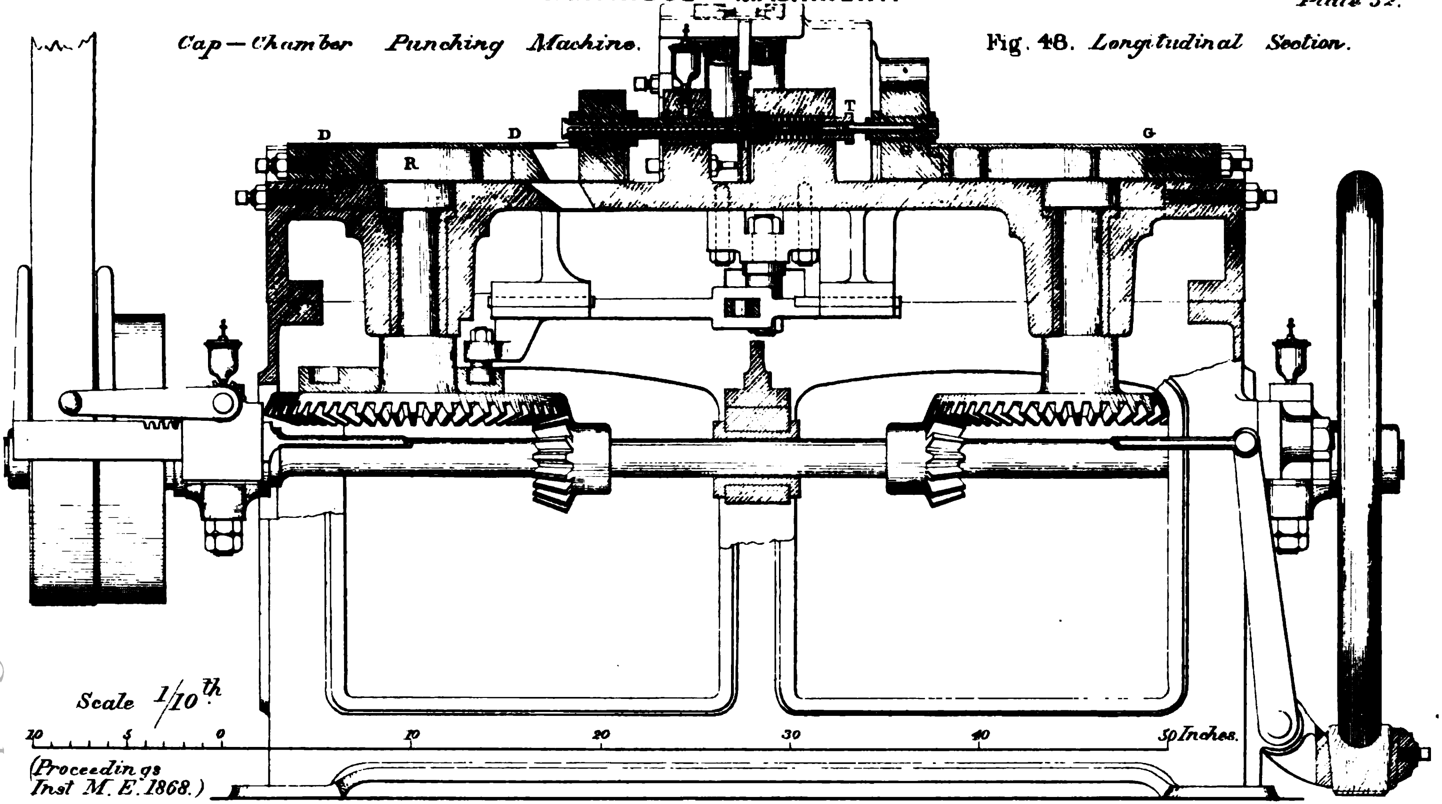
Scale 1/4th.

CARTRIDGE MACHINERY.

Plate 52.

Cap-Chamber Punching Machine.

Fig. 48. *Longitudinal Section.*



(Proceedings Inst M. E. 1868.)

CARTRIDGE MACHINERY.

Cap-Chamber Punching Machine.

Fig. 49. *Transverse Section.*

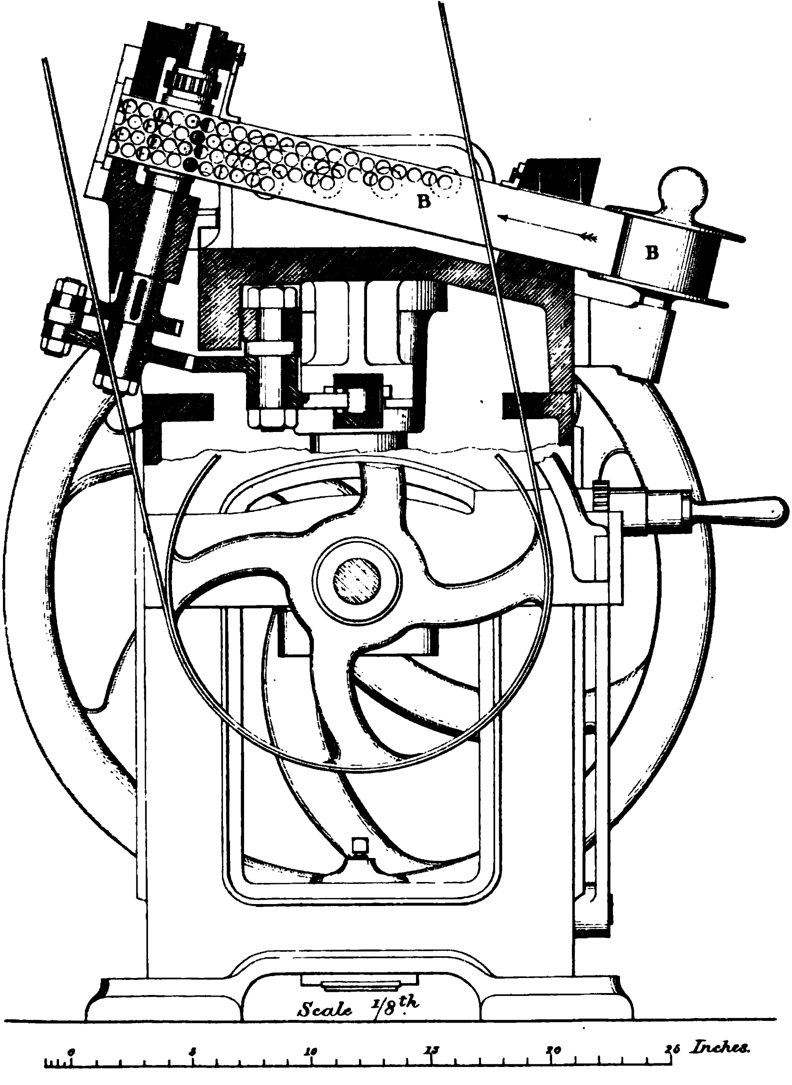
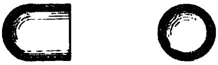


Fig. 50. *Cap-Chamber as delivered from machine.*



Full size.

(Proceedings Inst. M. E. 1868.)

CARTRIDGE MACHINERY. *Plate 53.*

Cap–Chamber Punching Machine.

Fig. 49. *Transverse Section.*

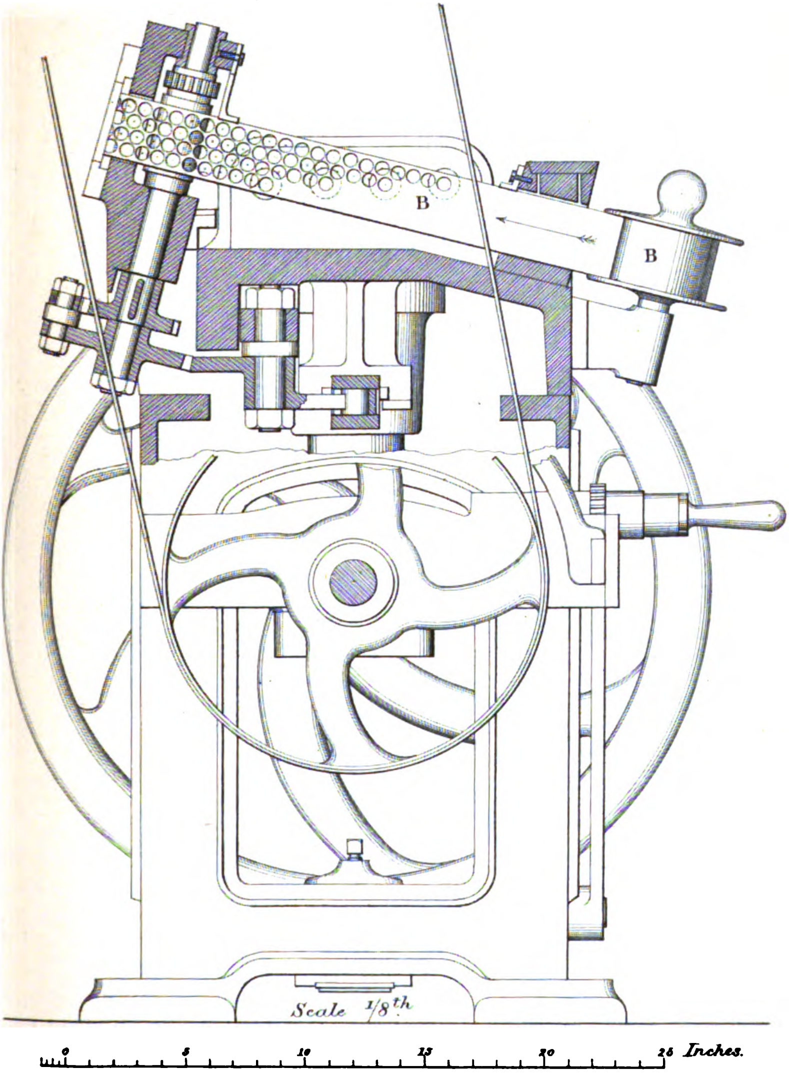
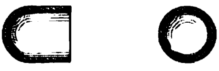


Fig. 50. *Cap–Chamber as delivered from machine.*



Full size.

CARTRIDGE MACHINERY.

Cap – Chamber Punching Machine.

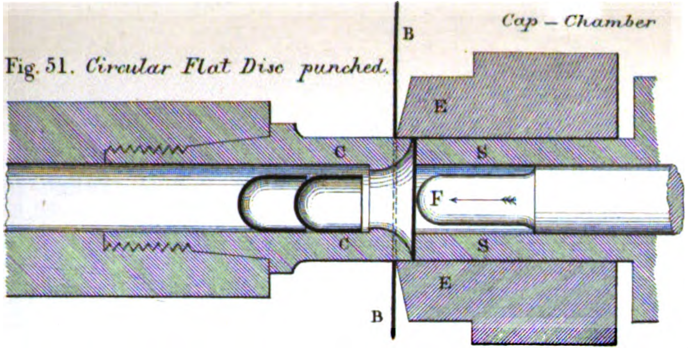


Fig. 51. *Circular Flat Disc punched.*

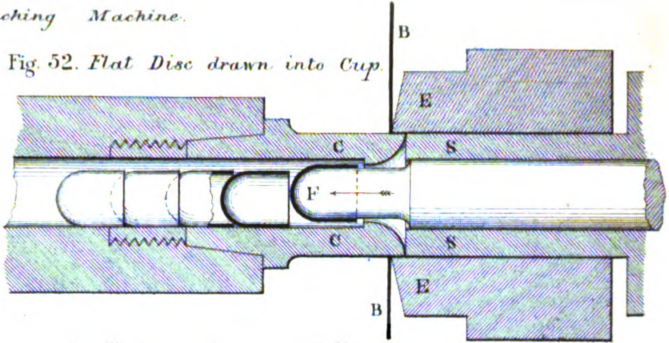
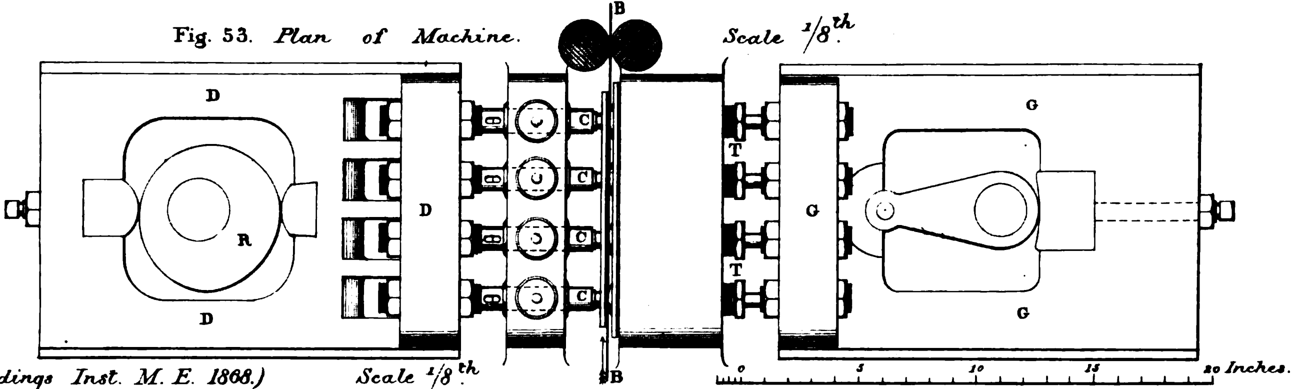


Fig. 52. *Flat Disc drawn into Cup.*

Longitudinal Sections of Punch and Bolster &c. Full size.

Fig. 53. *Plan of Machine.* *Scale 1/8th.*



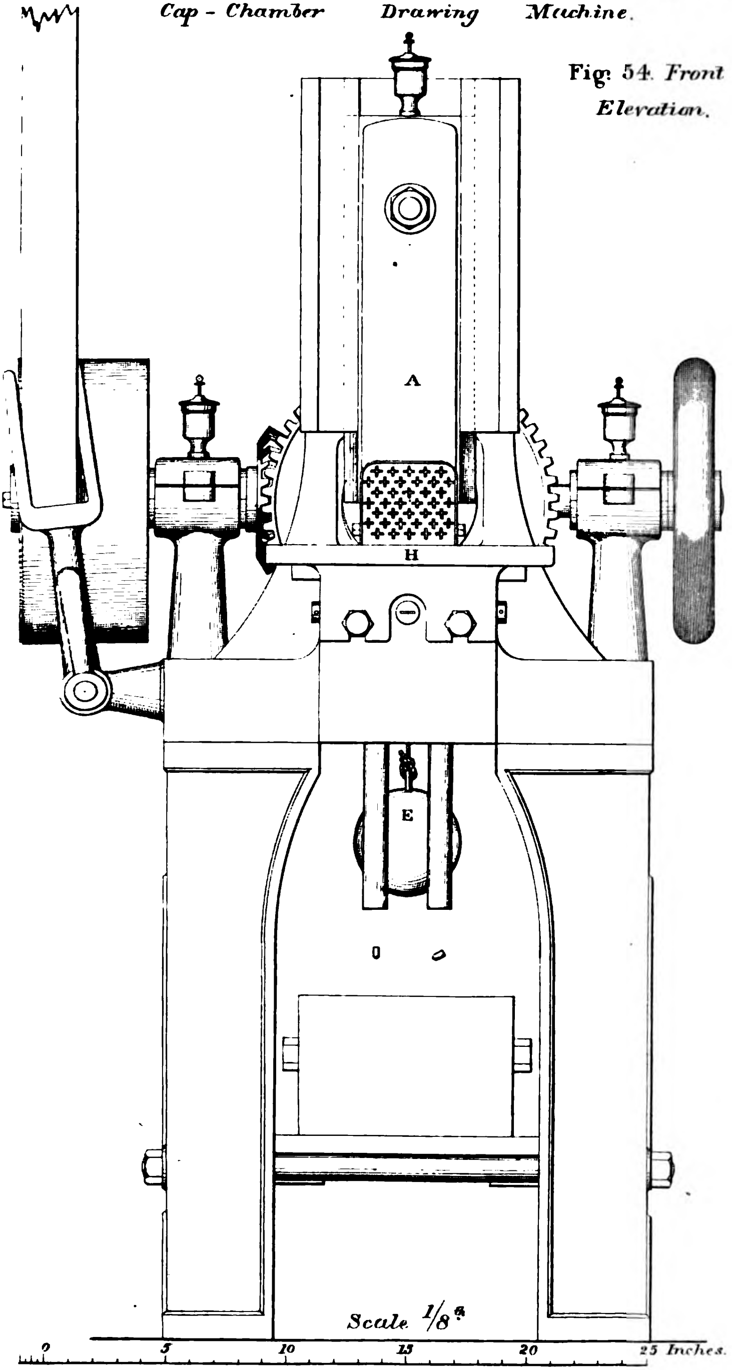
(Proceedings Inst. M. E. 1868.) *Scale 1/8th.*

CARTRIDGE MACHINERY.

Plate 55.

Cap-Chamber Drawing Machine.

Fig: 54. *Front Elevation.*



(Proceedings Inst. M. E. 1868.)

CARTRIDGE MACHINERY.

Cap-Chamber Drawing Machine.

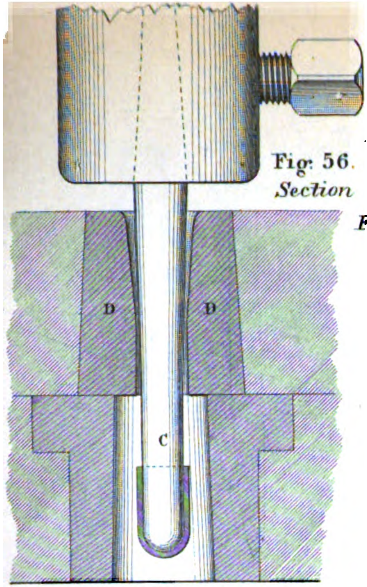


Fig. 56. Vertical Section of Bolster.
Full size.

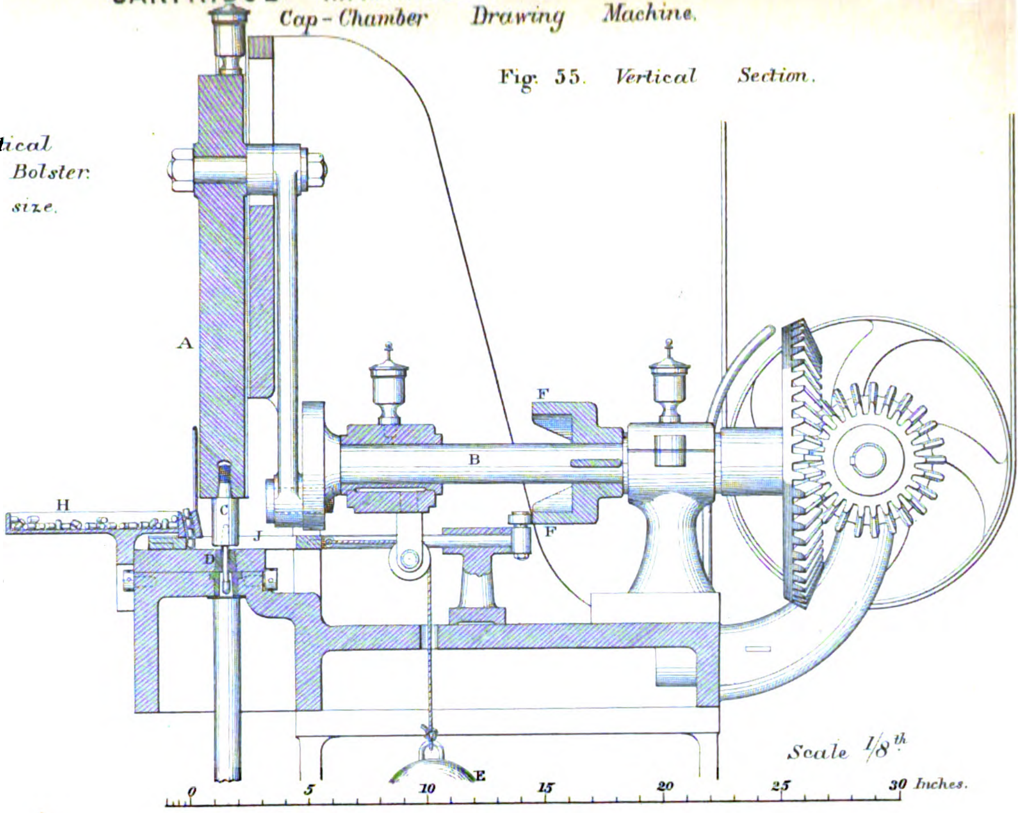


Fig. 55. Vertical Section.

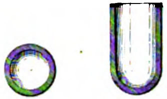


Fig. 57. Cap Chamber as delivered from machine.
Full size.

(Proceedings Inst. M.E. 1868.)

CARTRIDGE MACHINERY.

Cap - Chamber Trimming Machine.

Fig. 60. *Plan.*
Scale 1/8th.

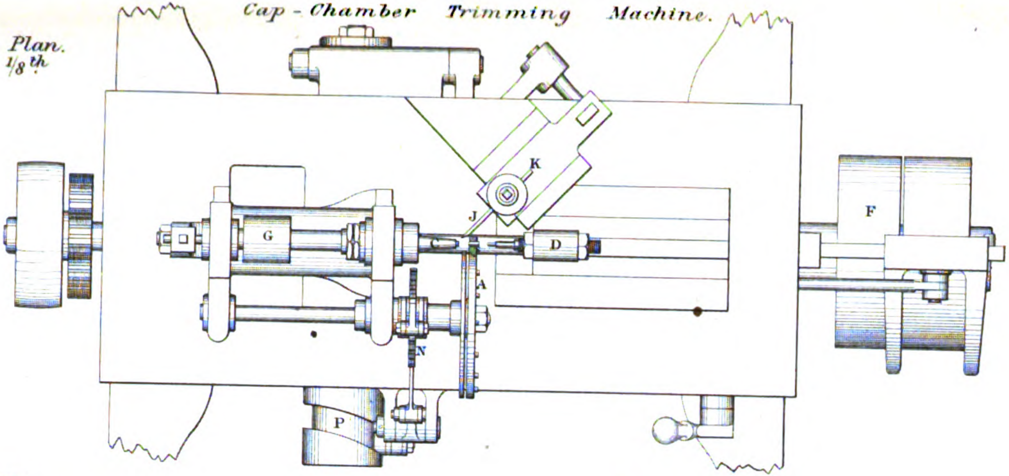
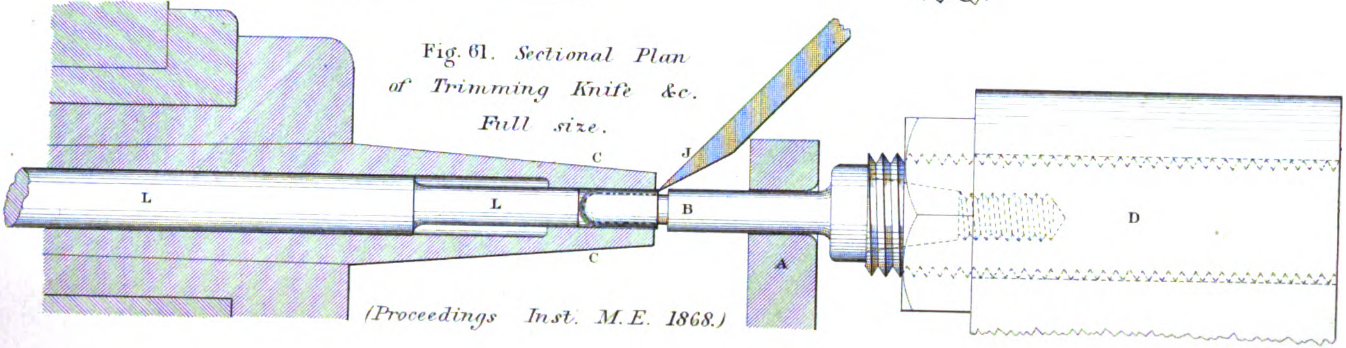


Fig. 61. *Sectional Plan of Trimming Knife &c. Full size.*



(Proceedings Inst. M.E. 1868.)

CARTRIDGE MACHINERY.

Cap-Chamber Flanging Machine.

Fig. 62. *Vertical Section.*

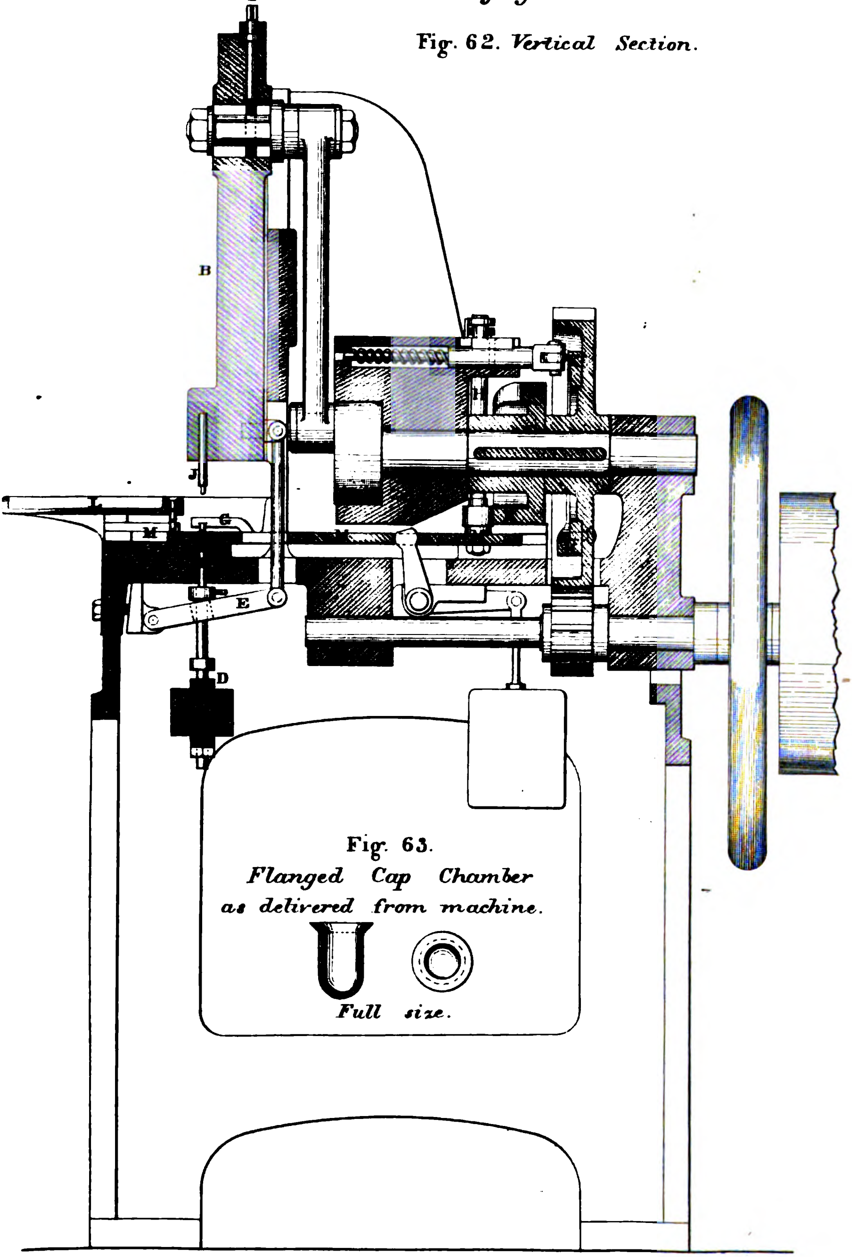


Fig. 63.
Flanged Cap Chamber as delivered from machine.

Full size.

(Proceedings Inst. M.E. 1868.)

Scale 1/8th

CARTRIDGE MACHINERY.

Plate 60.

Cap – Chamber Flanging Machine.

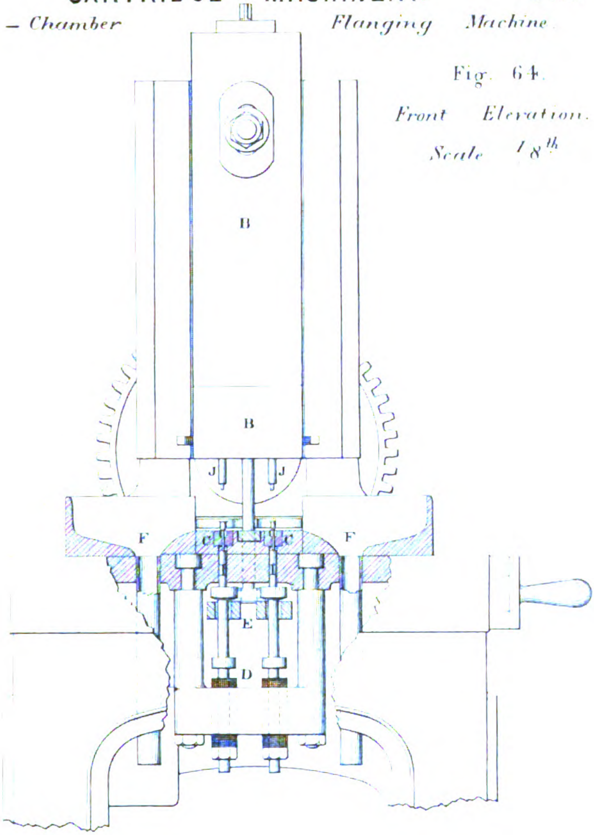


Fig. 64.

Front Elevation.

Scale 1/8th

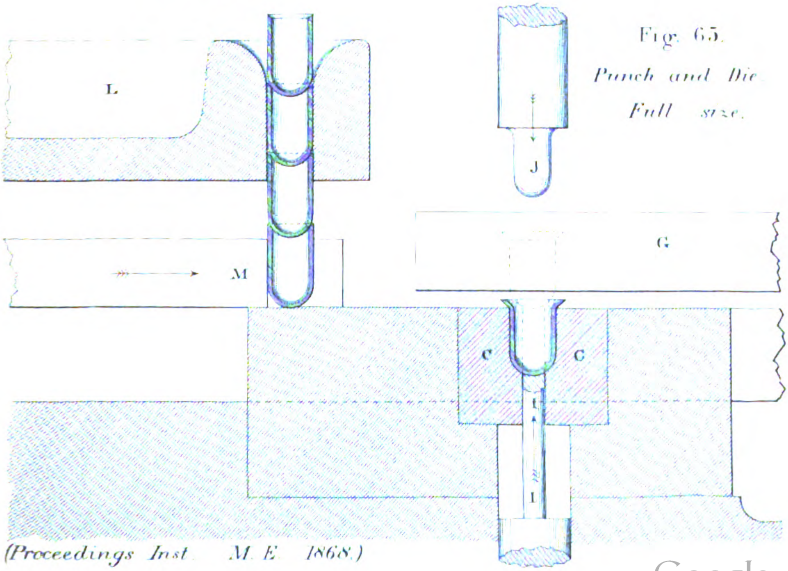


Fig. 65.

Punch and Die.

Full size.

(Proceedings Inst. M. E. 1868.)

CARTRIDGE MACHINERY. *Plate 61.*

Paper Wad Making Machine.

Fig. 66. *Side Elevation.*

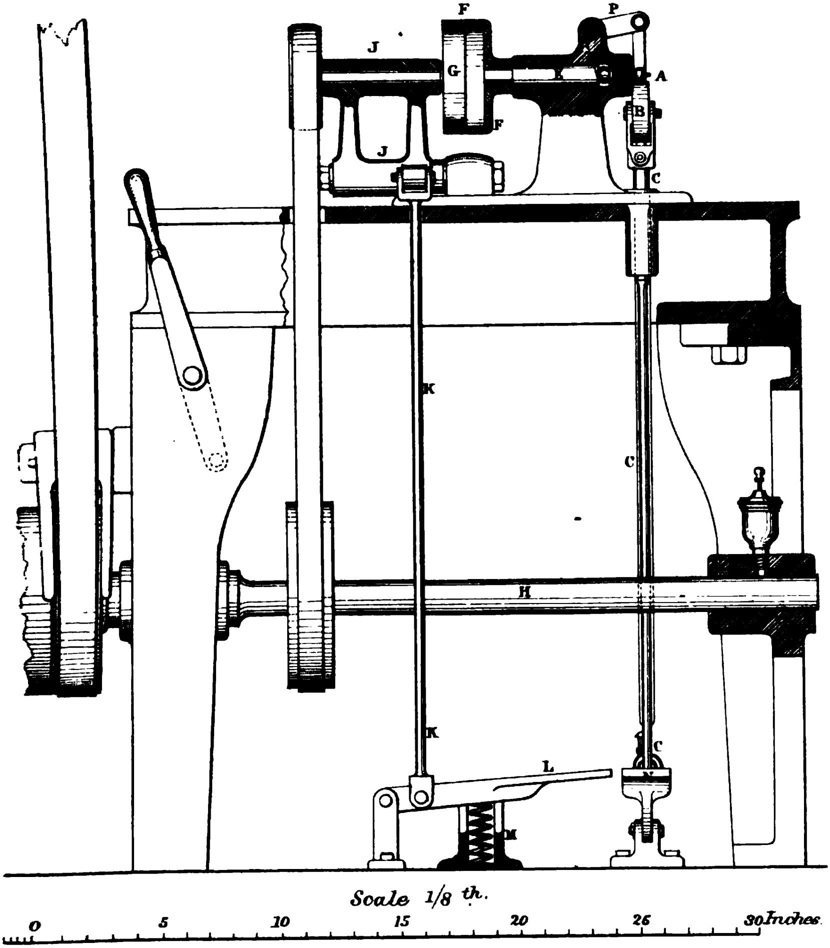
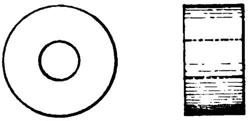


Fig. 67. *Paper Wad, as delivered from machine.*



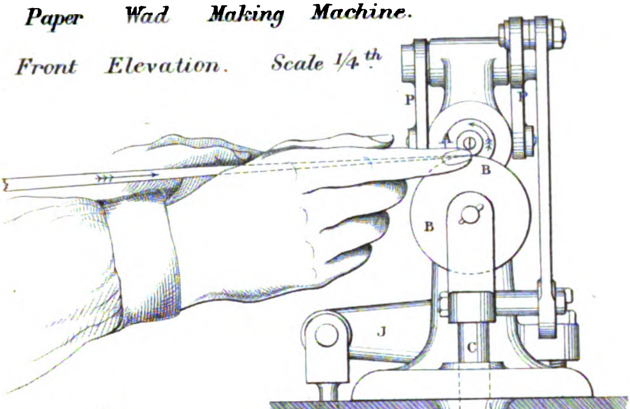
Full size.

(Proceedings Inst. M. E. 1868.)

CARTRIDGE MACHINERY.

Paper Wad Making Machine.

Fig. 68. *Front Elevation. Scale 1/4th.*



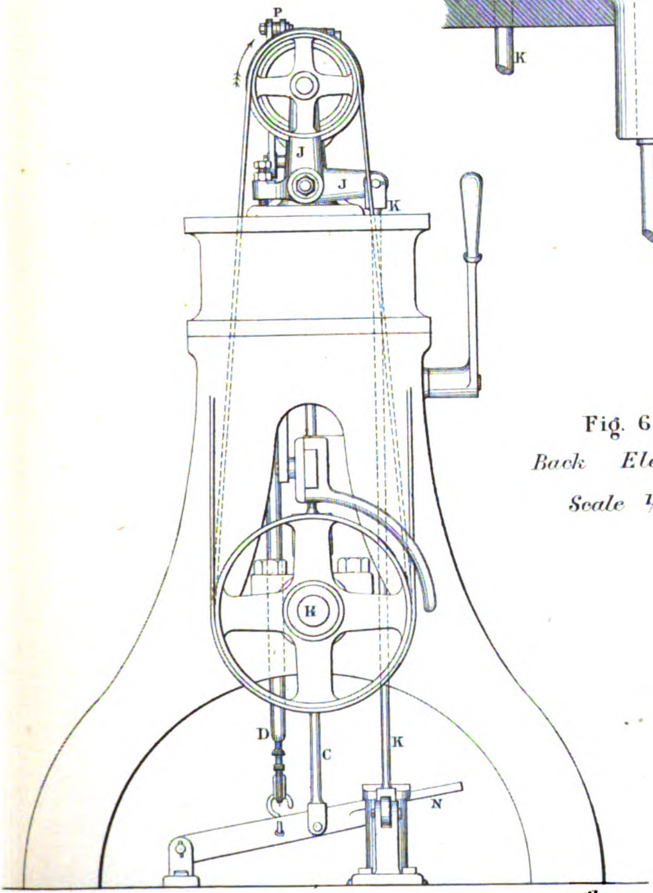


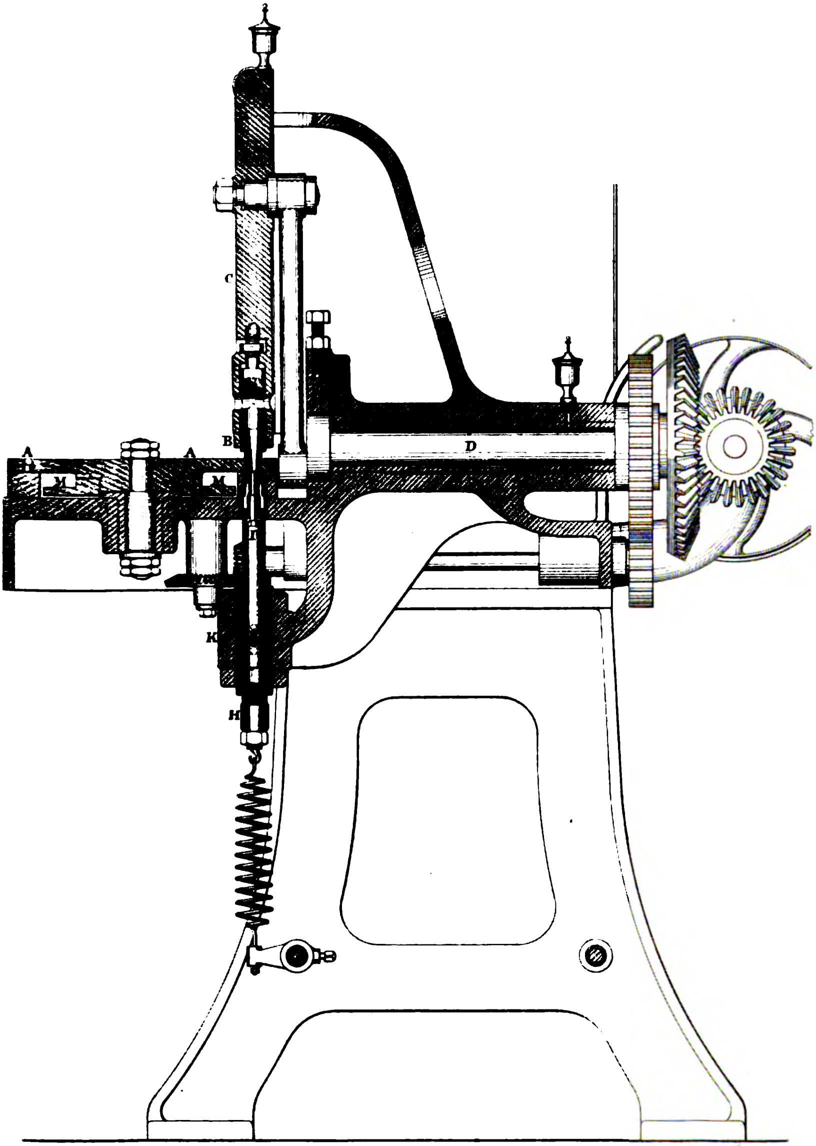
Fig. 69.
Back Elevation.
Scale 1/8th.

Scale 1/8th.
0 5 10 15 20 25 30 Inches.

CARTRIDGE MACHINERY. *Plate 63.*

Paper Wad Pressing Machine.

Fig. 70. *Longitudinal Section.*



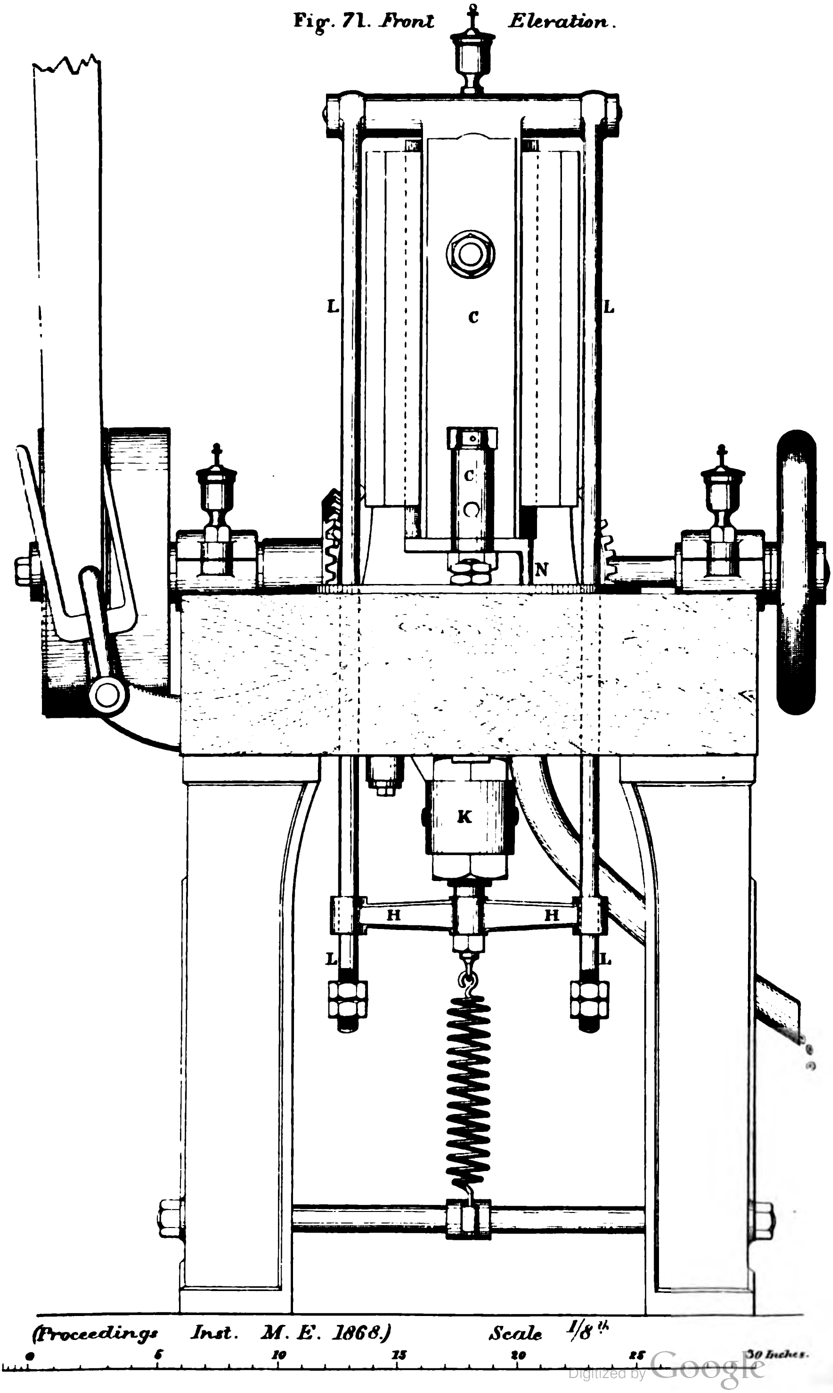
(Proceedings Inst. M. E. 1868.) *Scale* $1/10^{th}$

0 5 10 15 20 25 30 *Inches.*

CARTRIDGE MACHINERY.

Paper Wad Pressing Machine.

Fig. 71. Front Elevation.



Scale 1/8th

CARTRIDGE MACHINERY.

Plate 65.

Paper Wad Pressing Machine.

Fig. 72. *Scale 1/4th*
Plan of Star Wheel for rotating the Feed Table.

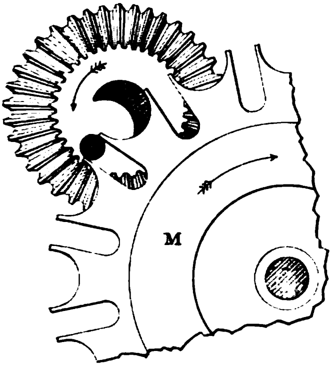
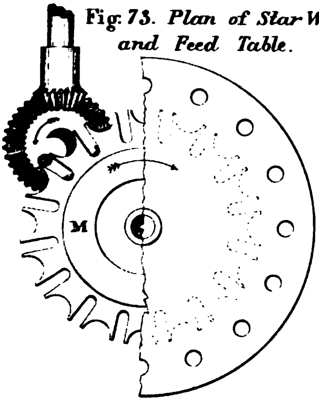
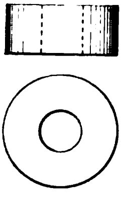


Fig. 73. *Plan of Star Wheel and Feed Table.*



Scale 1/8th

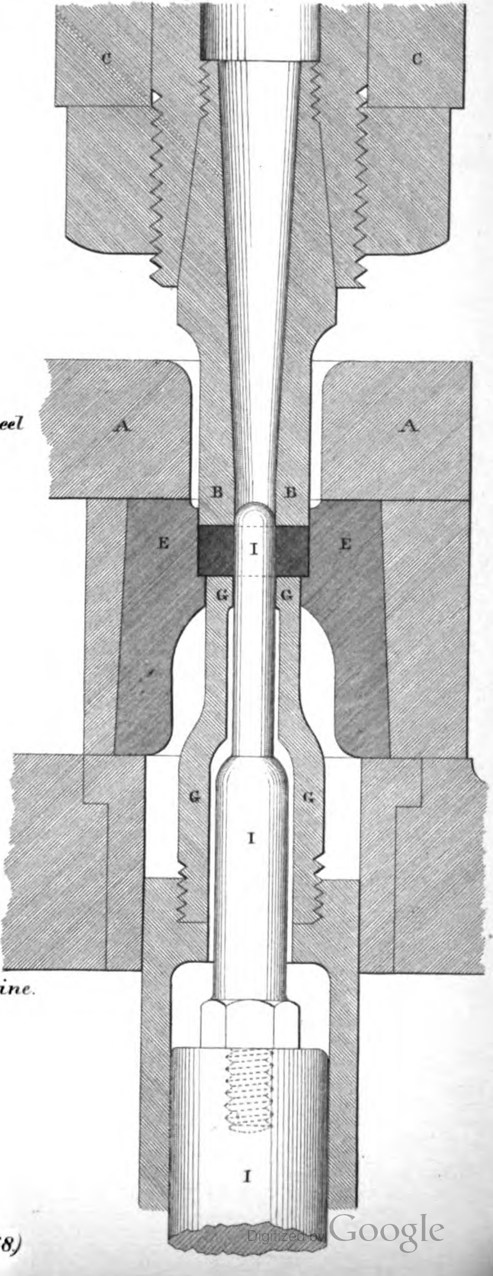
Fig. 75. *Pressed Wad as delivered from machine.*



Full size.

(Proceedings Inst. M. E. 1868)

Fig. 74. *Full size*
Vertical Section of Pressing Punch and Die.



CARTRIDGE MACHINERY.

Hand Lever Press for fixing body of Cartridge together.

Fig. 76. *Longitudinal Section.* *Scale 1/4th.*

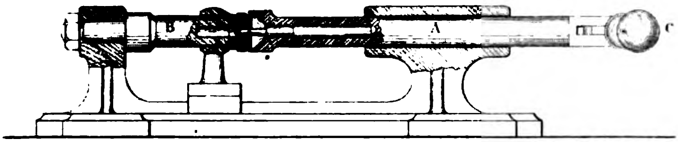
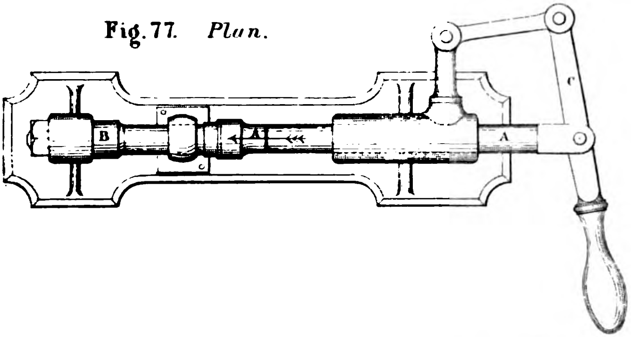


Fig. 77. *Plan.*



Choking Apparatus for fixing Bullet in Cartridge Case.

Fig. 78. *Side Elevation.*

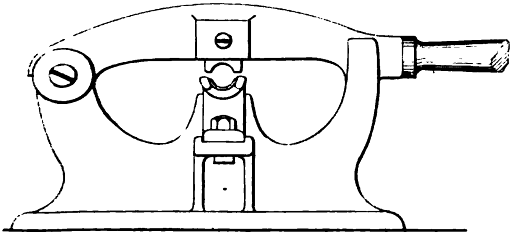


Fig. 79. *Transverse Section.*

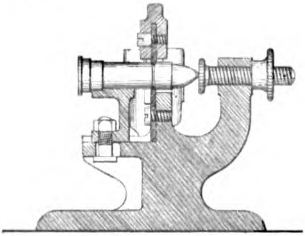
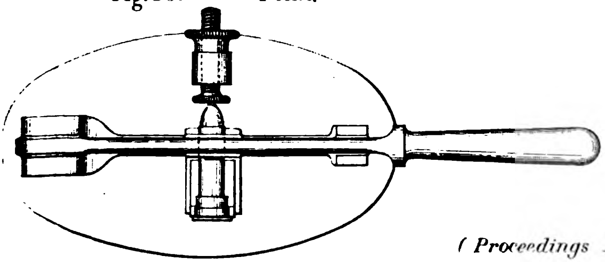
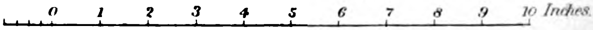


Fig. 80. *Plan.*



(Proceedings Inst. M. E. 1868.)

Scale 1/4th.



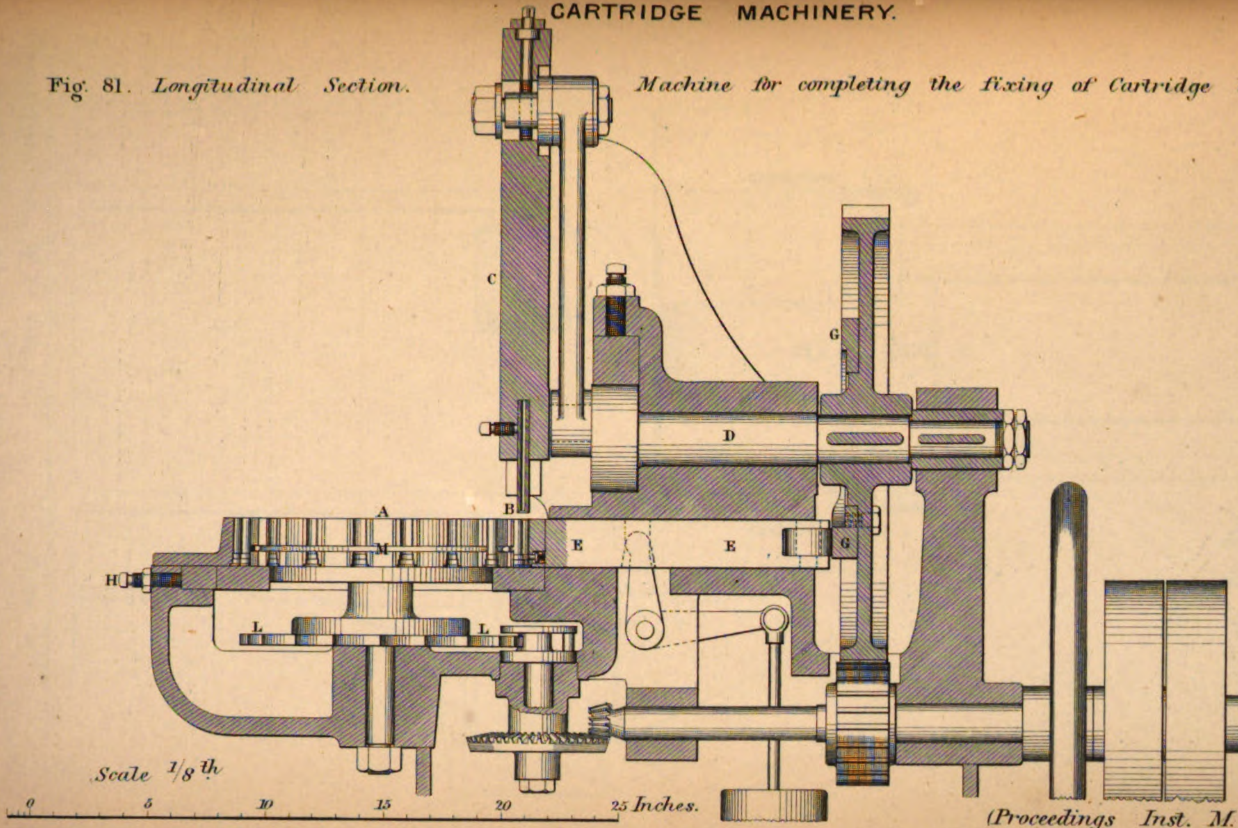
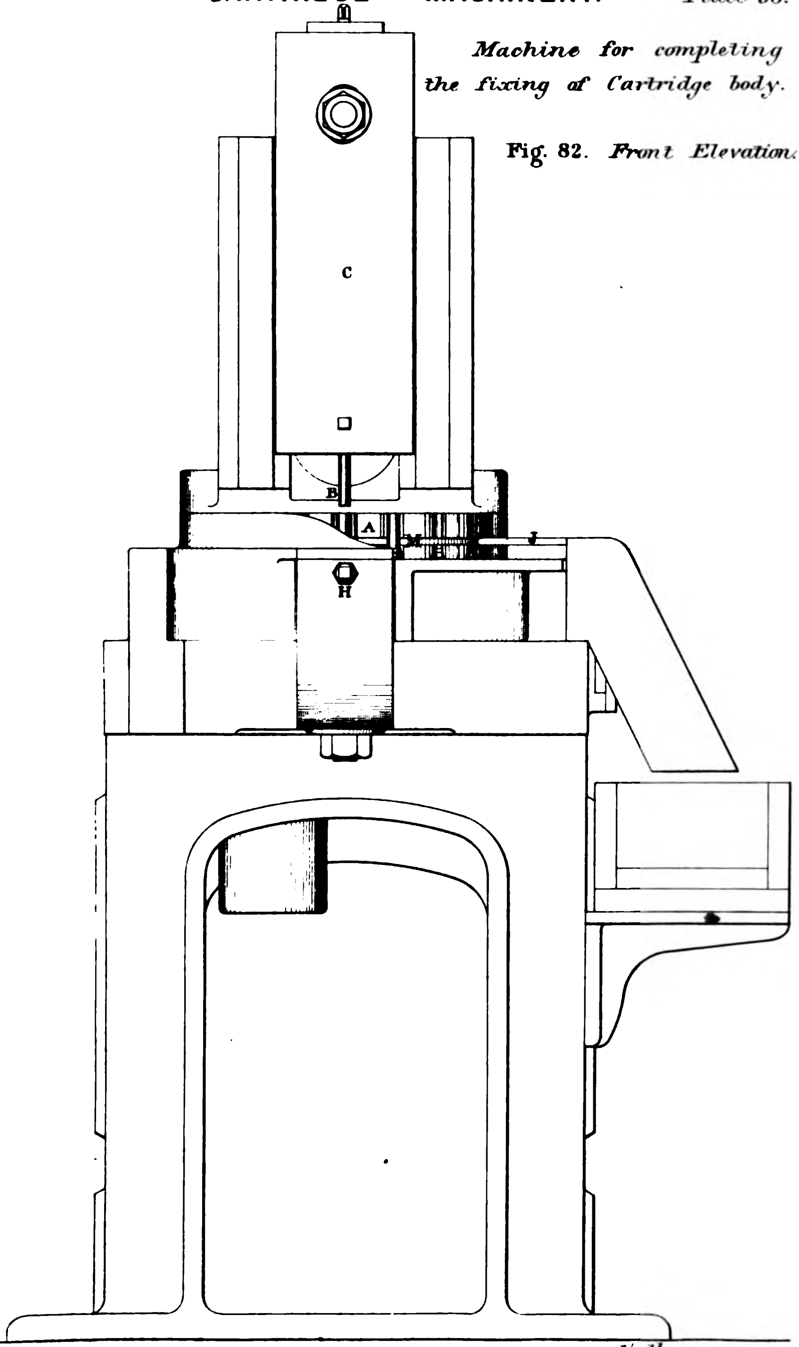


Fig. 81. *Longitudinal Section.* *Machine for completing the fixing of Cartridge body.*

(Proceedings Inst. M. E. 1868.)

Machine for completing the fixing of Cartridge body.

Fig. 82. *Front Elevation.*



(Proceedings Inst. M. E. 1868.)

Scale $1/8^{th}$.

0 5 10 15 20 25 *Inches.*

Machine for completing the fixing of Cartridge body.

Fig. 83. *Plan of Feed Plate.*

Scale 1/8th.

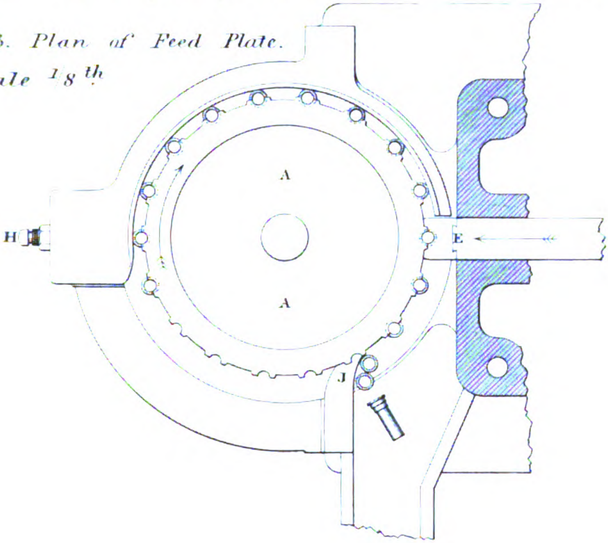
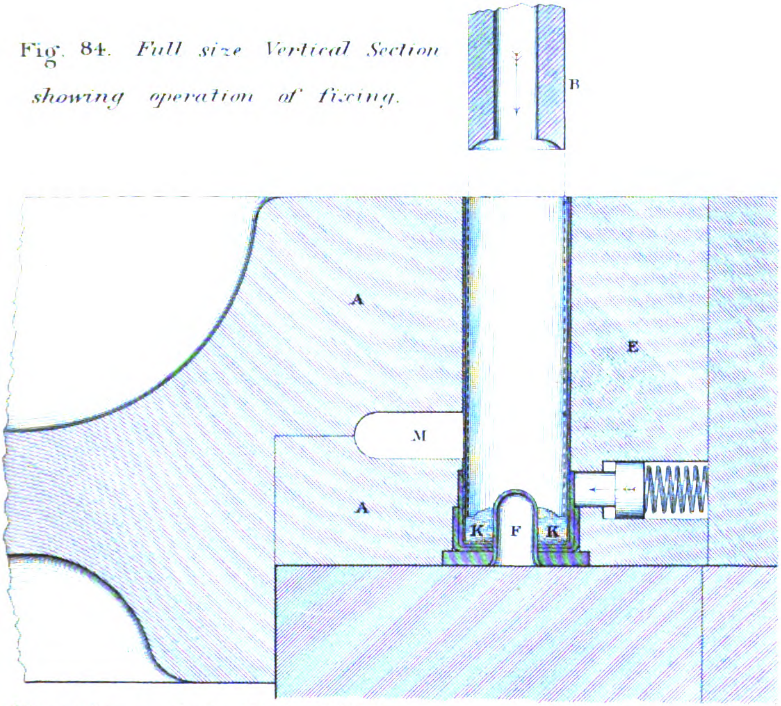


Fig. 84. *Full size Vertical Section showing operation of fixing.*



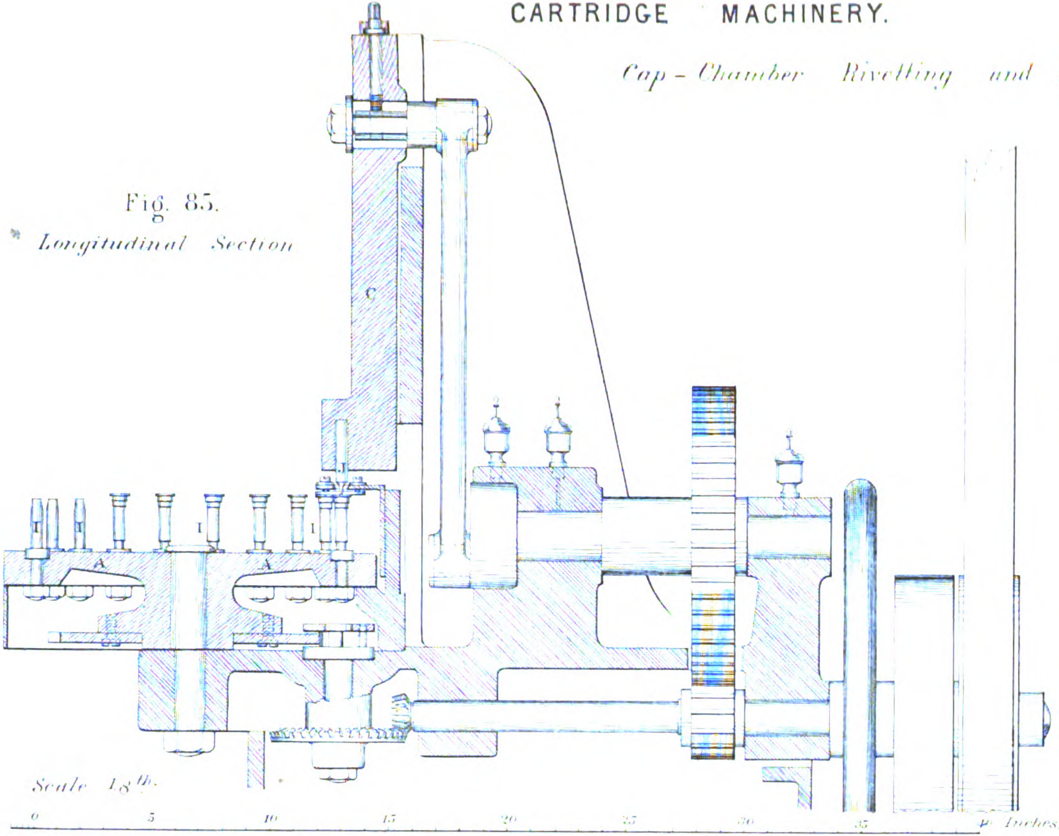
(Proceedings Inst. M. E. 1868.) *Full size.*

CARTRIDGE MACHINERY.

Cap-Chamber Rivetting and Piercing Machine.

Fig. 85.

Longitudinal Section



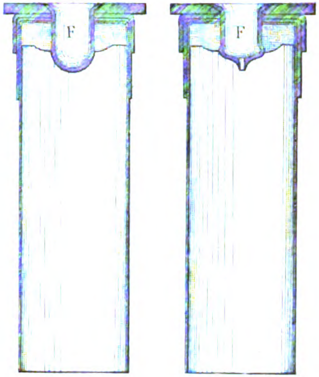
Scale 1/8th.

Inches. (*Proceedings Inst. M. E. 1868*)

Full size Sections of Cartridge Case.

Fig. 86. *Before Rivetting.*

Fig. 87. *After Rivetting and Piercing.*



Thicknesses magnified.

CARTRIDGE MACHINERY.

Cap-Chamber Rivetting and Piercing Machine.

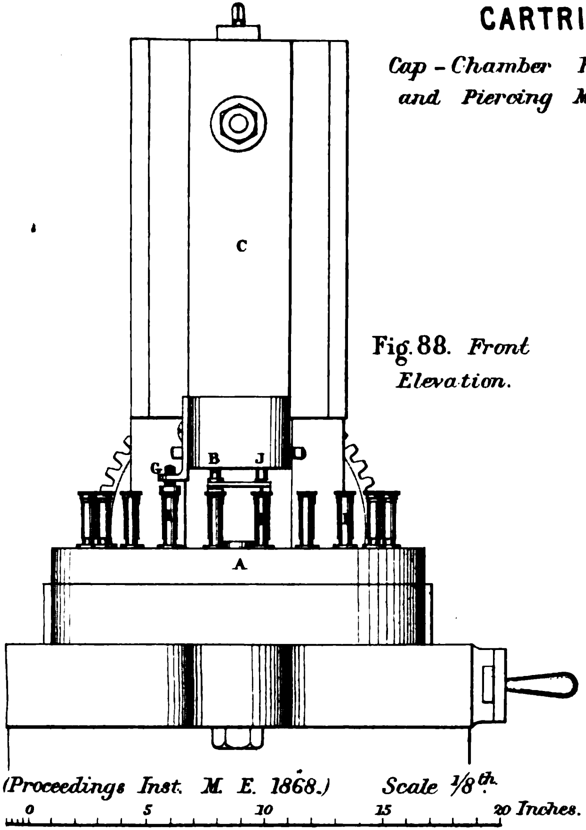


Fig. 88. *Front Elevation.*

(Proceedings Inst. M. E. 1868.) *Scale 1/8th.*

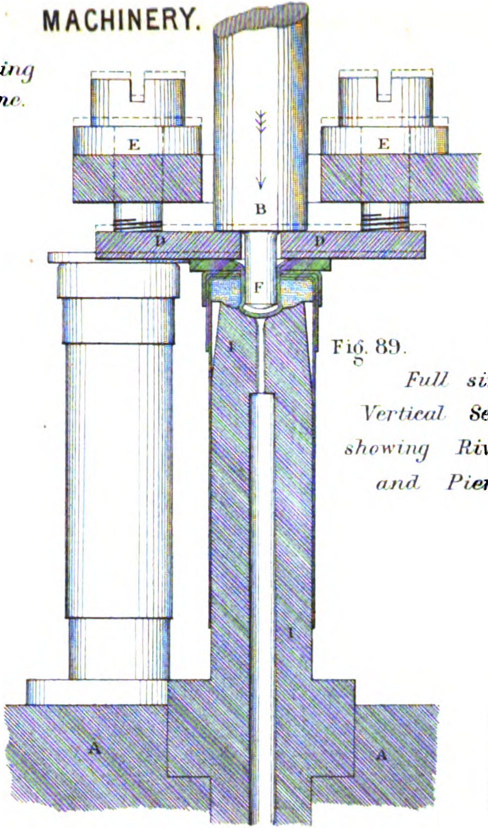


Fig. 89.

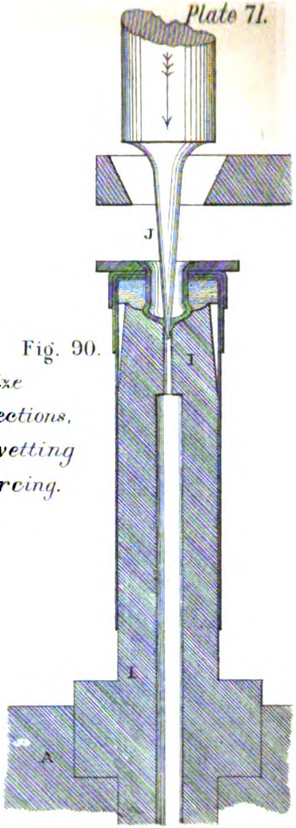


Fig. 90.

Full size Vertical Sections, showing Rivetting and Piercing.

CARTRIDGE MACHINERY.

Plate 72.

Capping Machine.

Fig. 91. *Plan.*

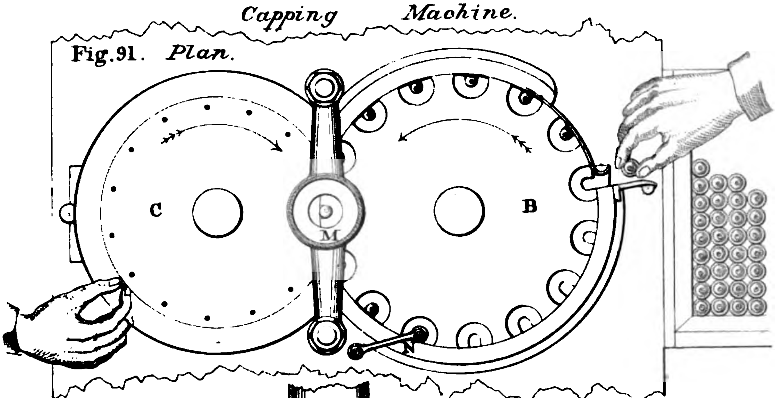
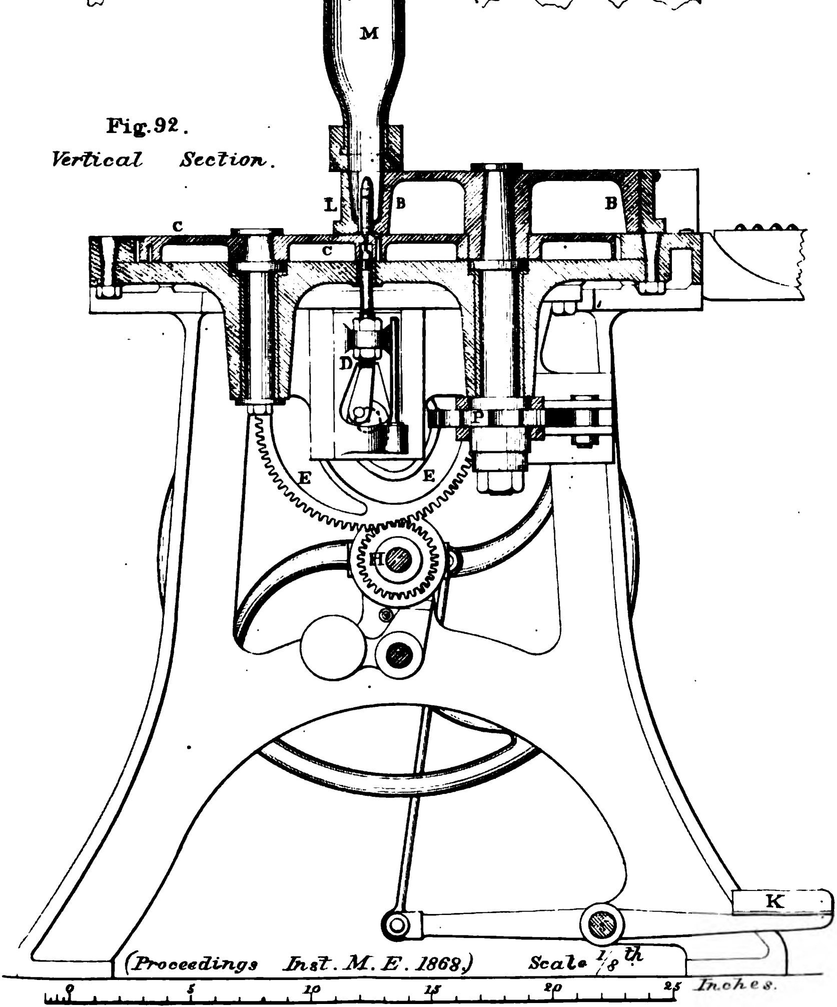


Fig. 92.

Vertical Section.



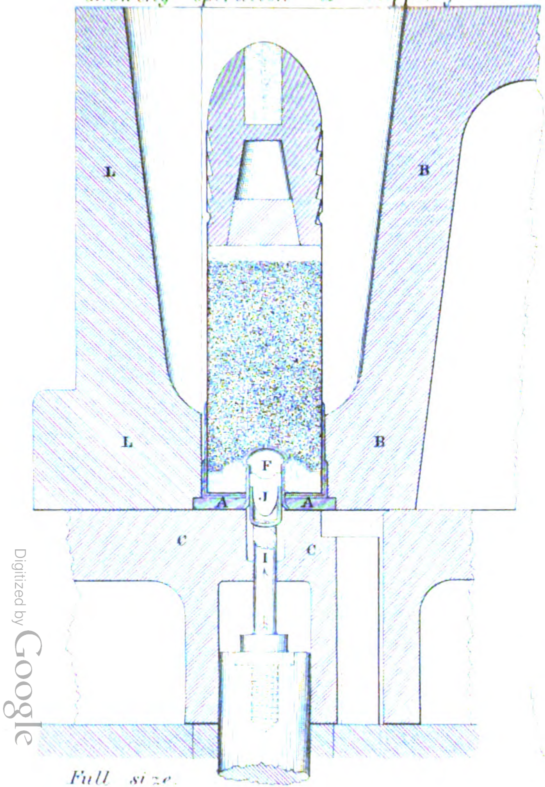
(Proceedings Inst. M. E. 1868.) Scale $\frac{1}{8}$th.

CARTRIDGE MACHINERY

Plate 73.

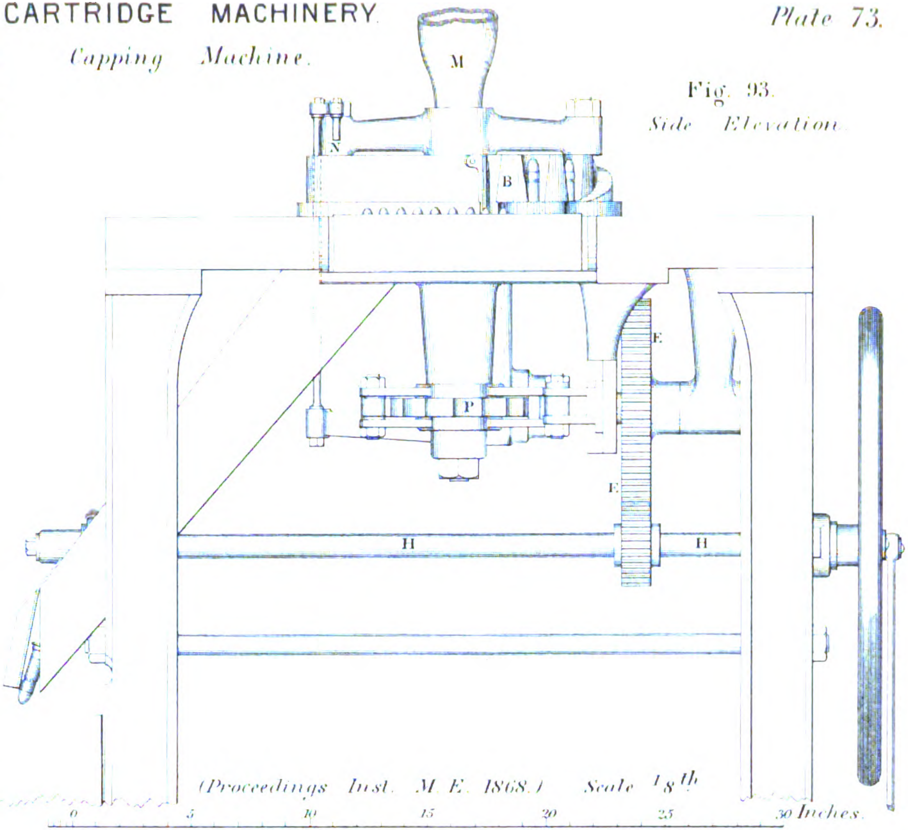
Capping Machine.

Fig. 94. *Full size Vertical Section showing operation of Capping.*



Full size.

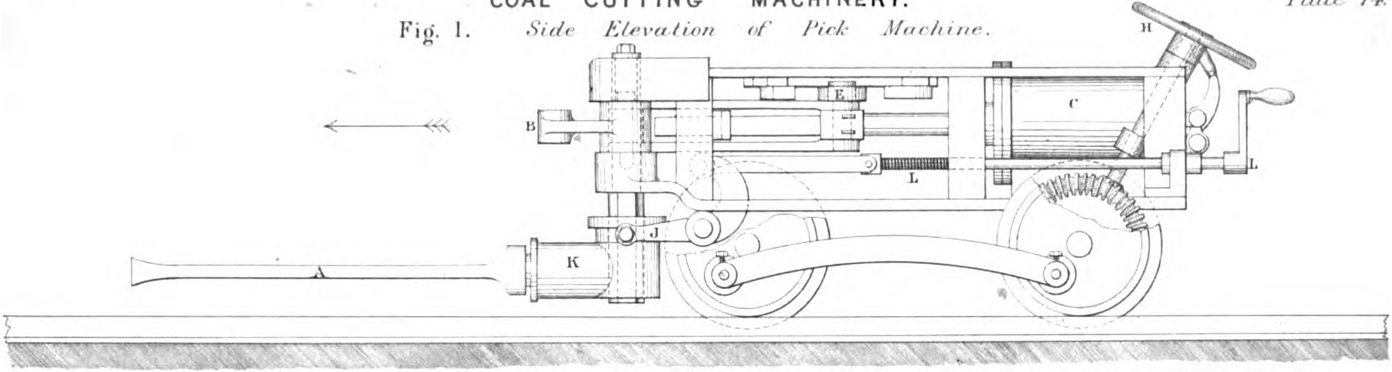
Fig. 93.
Side Elevation.



(Proceedings Inst. M. E. 1868.) *Scale 1/8th*

COAL CUTTING MACHINERY.

Fig. 1. *Side Elevation of Pick Machine.*



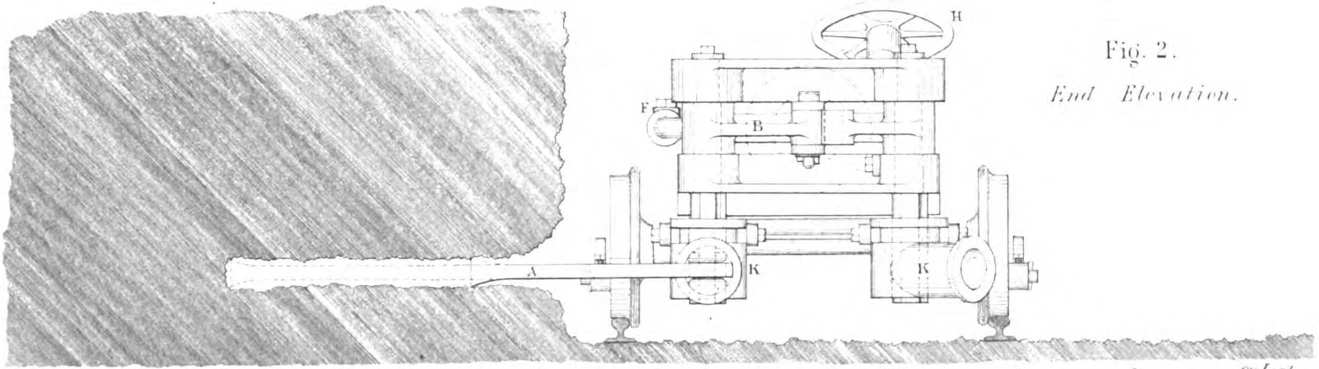


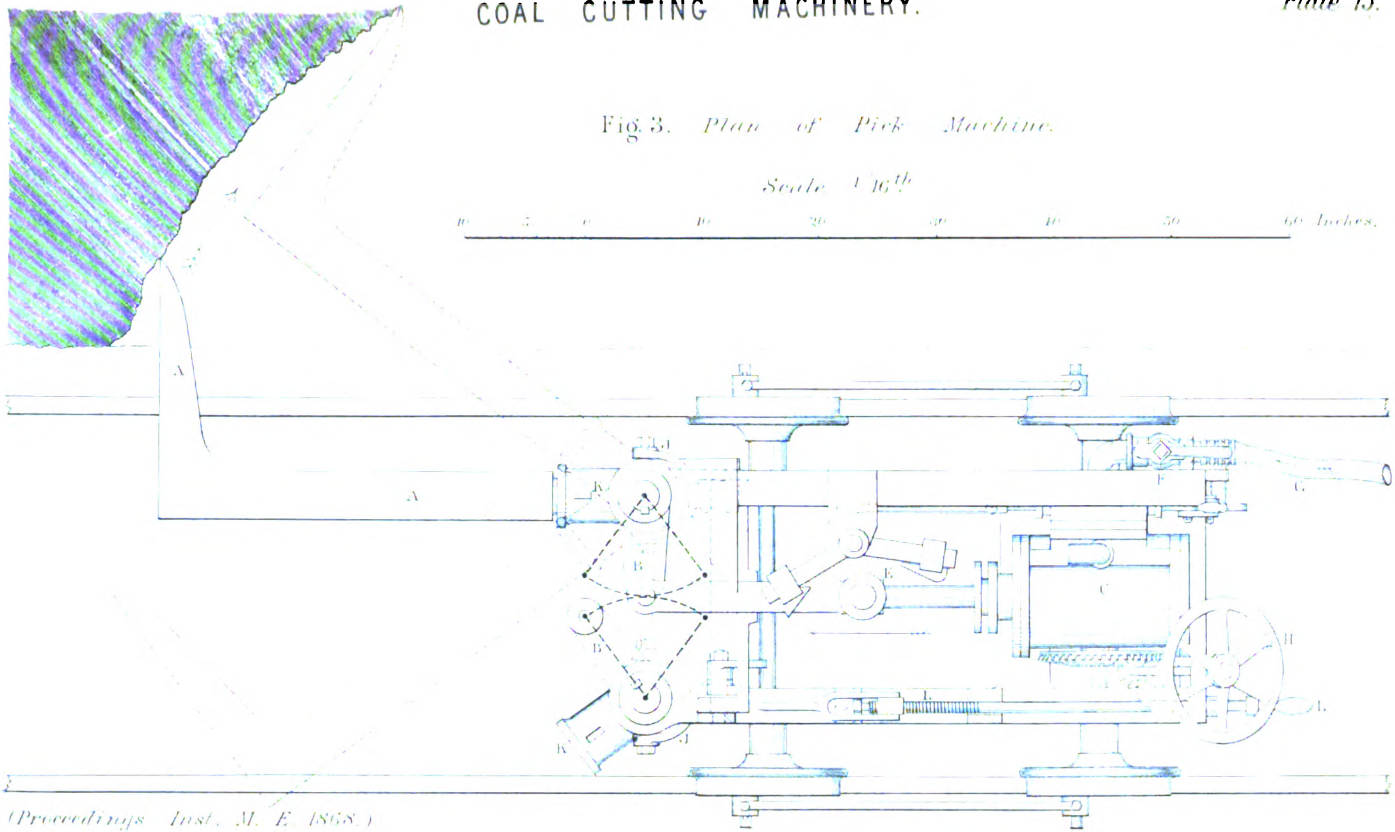
Fig. 2. *End Elevation.*

(Proceedings Inst. M. E. 1868.) *Scale* $^{1}/_{16}$th 10 5 0 10 20 30 40 50 60 *Inches.*

COAL CUTTING MACHINERY.

Fig. 3. *Plan of Pick Machine.*

Scale $^{1}/_{16}$th

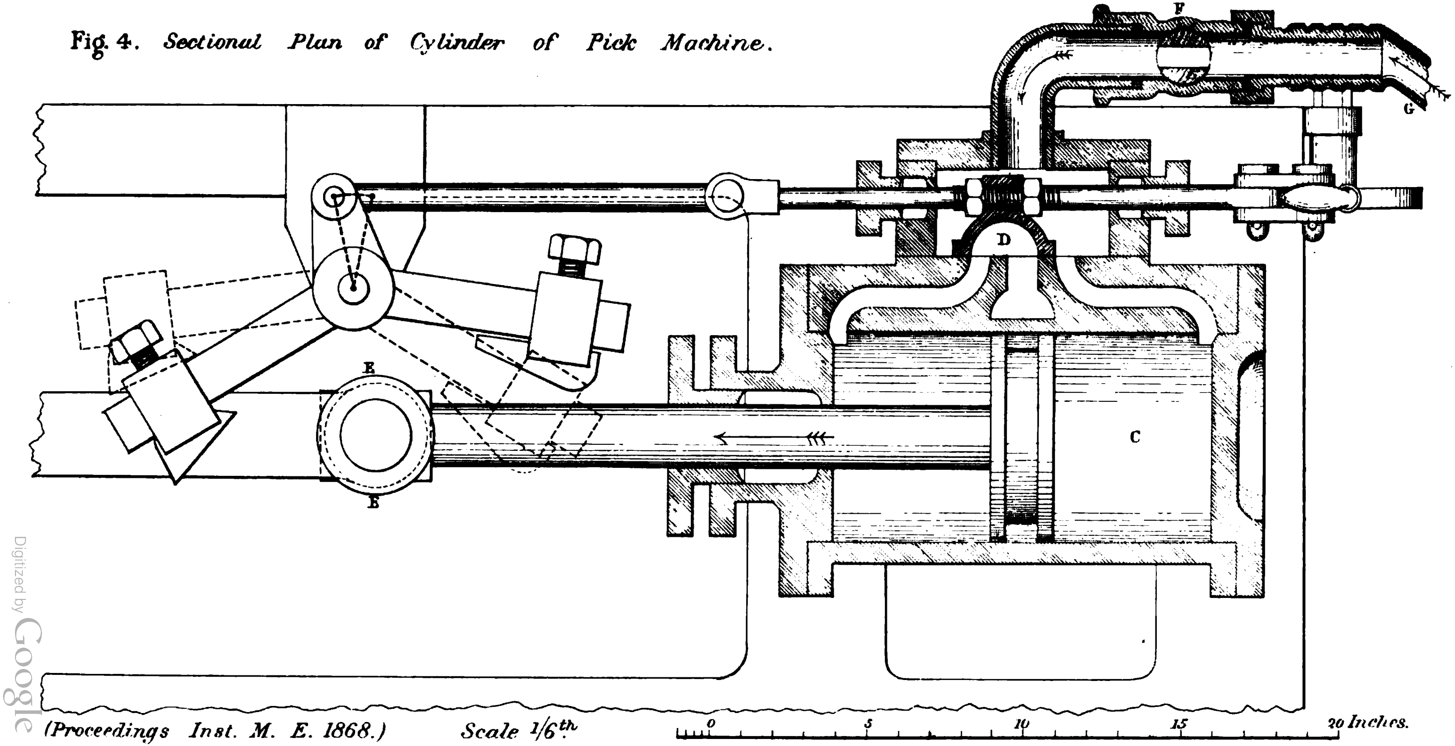


(Proceedings Inst. M. E. 1868.)

COAL CUTTING MACHINERY.

Plate 76.

Fig. 4. *Sectional Plan of Cylinder of Pick Machine.*

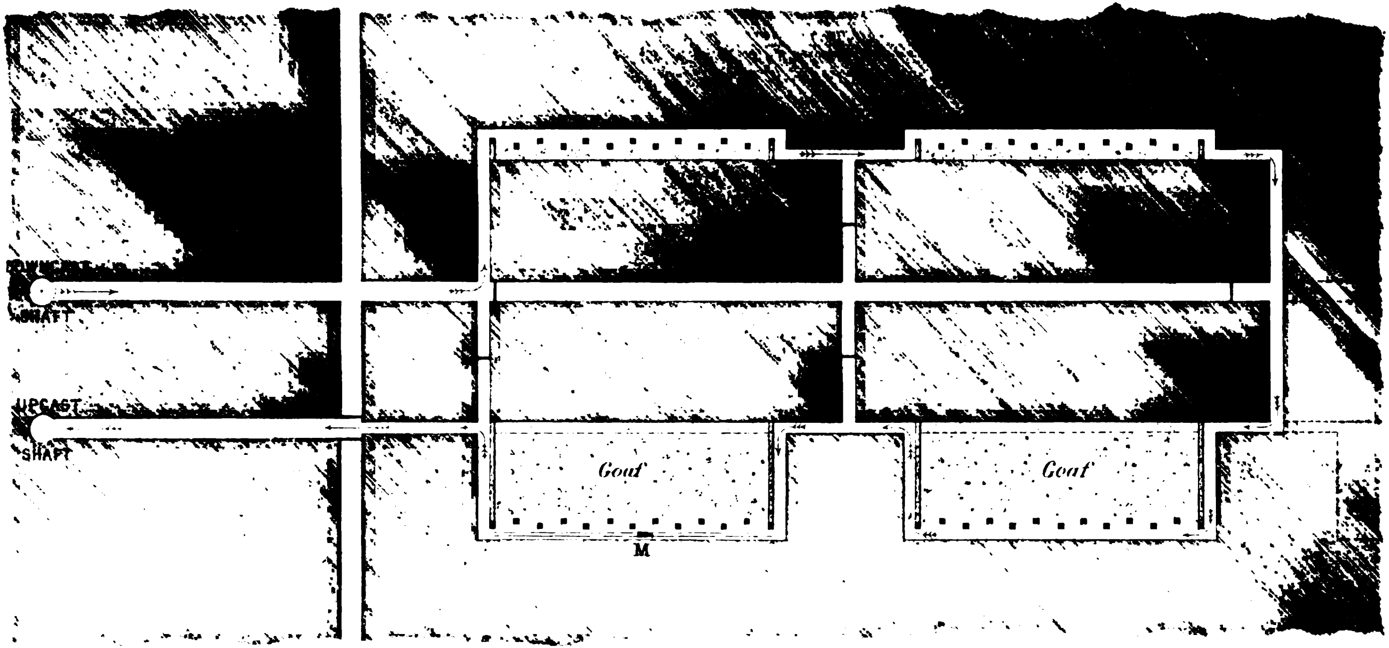


(Proceedings Inst. M. E. 1868.) *Scale 1/6th.*

COAL CUTTING MACHINERY.

Plate 77.

Fig. 5. *Plan of Working of Colliery by Pick Machine.*



(Proceedings Inst. M. E. 1868.) *Scale 1/1100th.*

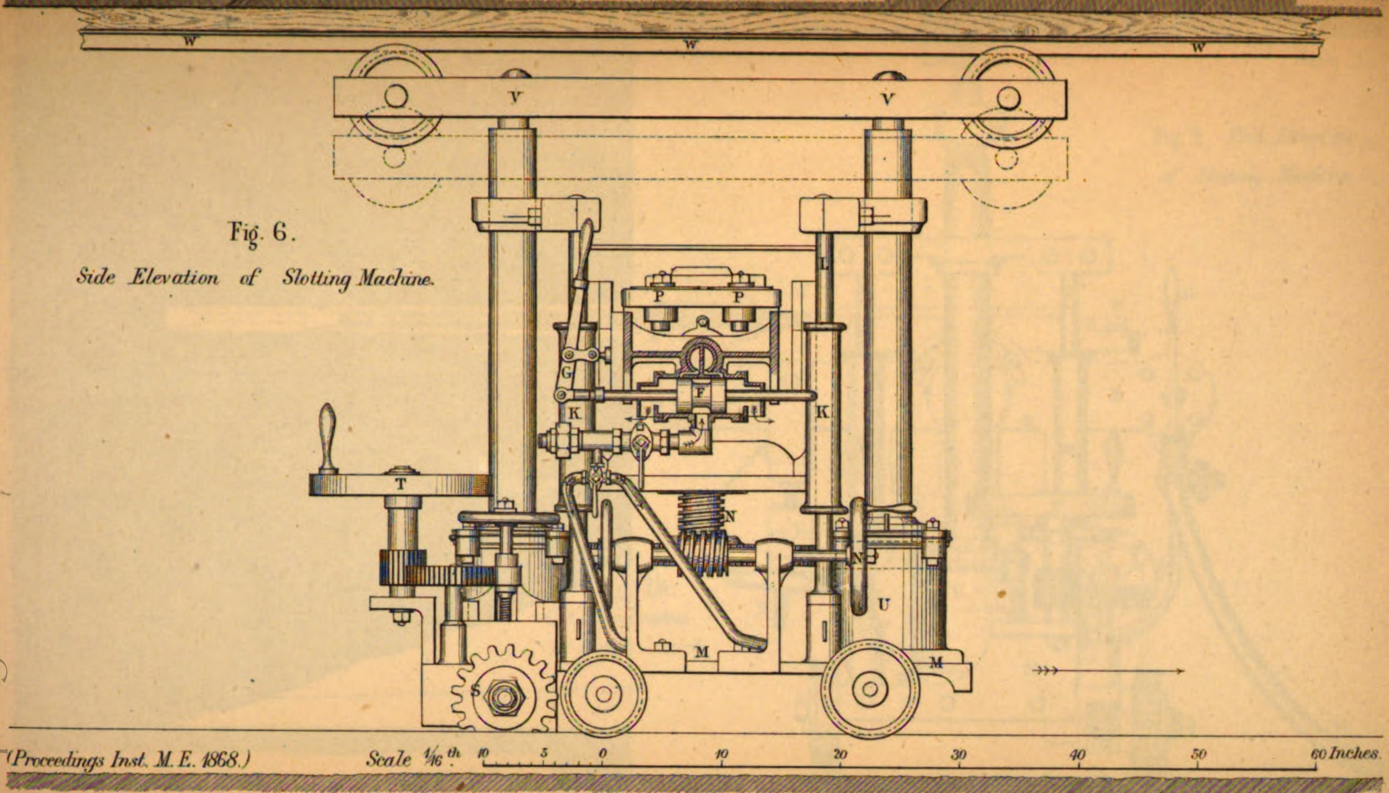


Fig. 6.

Side Elevation of Slotting Machine.

(*Proceedings Inst. M. E. 1868.*)

COAL CUTTING MACHINERY.

Plate 79.

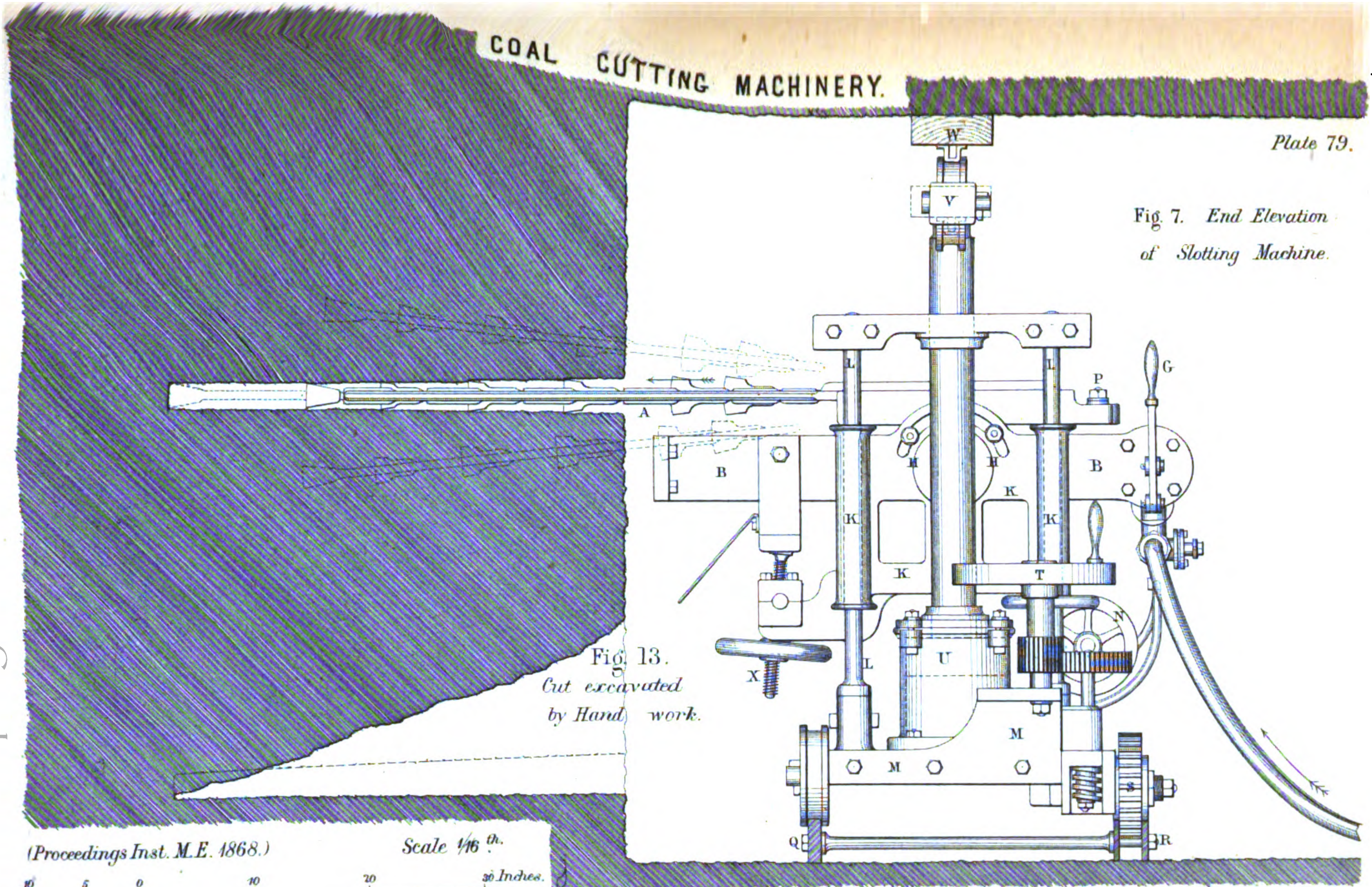


Fig. 7. *End Elevation of Slotting Machine.*

Fig. 13. *Cut excavated by Hand work.*

(Proceedings Inst. M.E. 1868.)

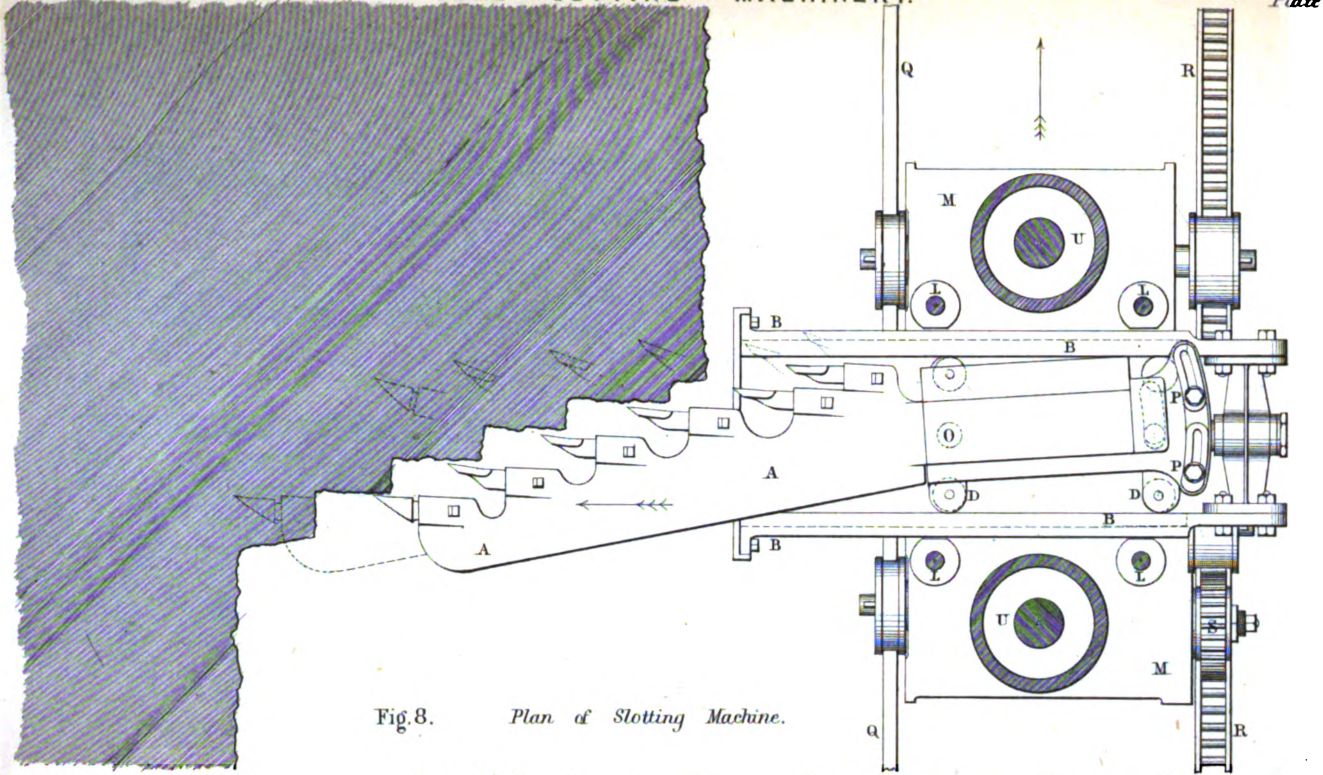


Fig. 8. *Plan of Slotting Machine.*

Scale 1/16 th.

COAL CUTTING MACHINERY.

Fig. 9. Sectional Plan of Cylinder of Slotting Machine. Scale 1/8 th.

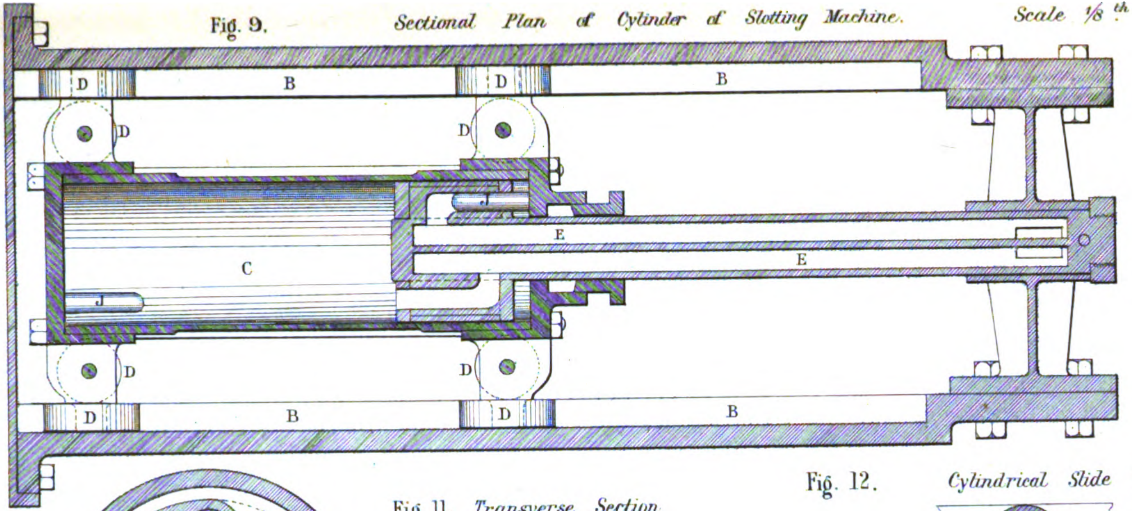


Fig. 10. Transverse Section of Piston. Scale 1/4 th.

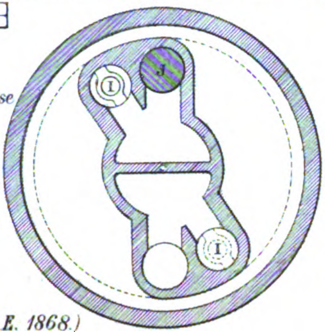
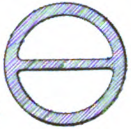
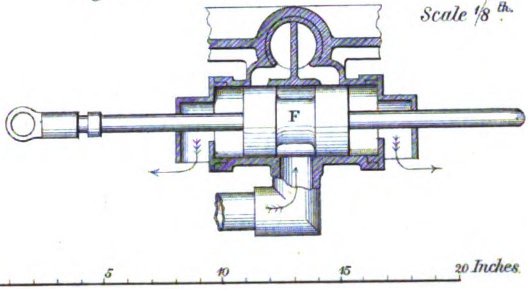


Fig. 11. Transverse Section of Piston-rod.



Scale 1/4 th.

Fig. 12. Cylindrical Slide Valve. Scale 1/8 th.



Scale 1/8 th

(Proceedings Inst. M. E. 1868.)

WIRE-ROPE TRAVELLING CRANE.

Fig. 1. *Transverse Section of Traveller.*

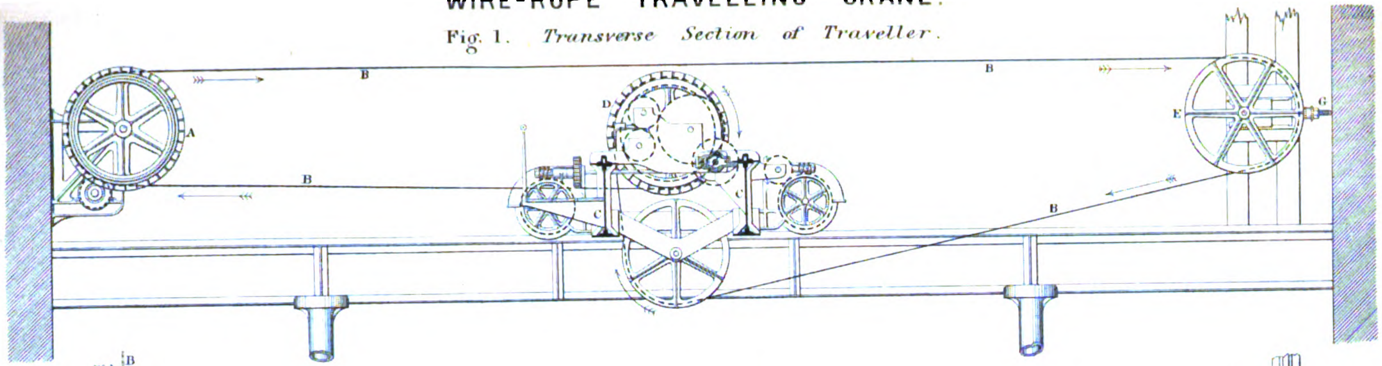
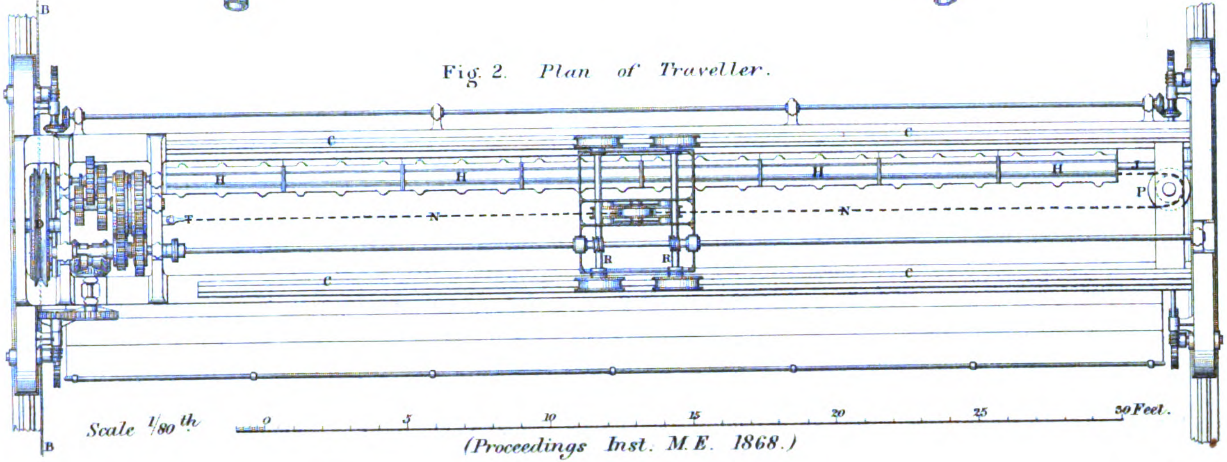


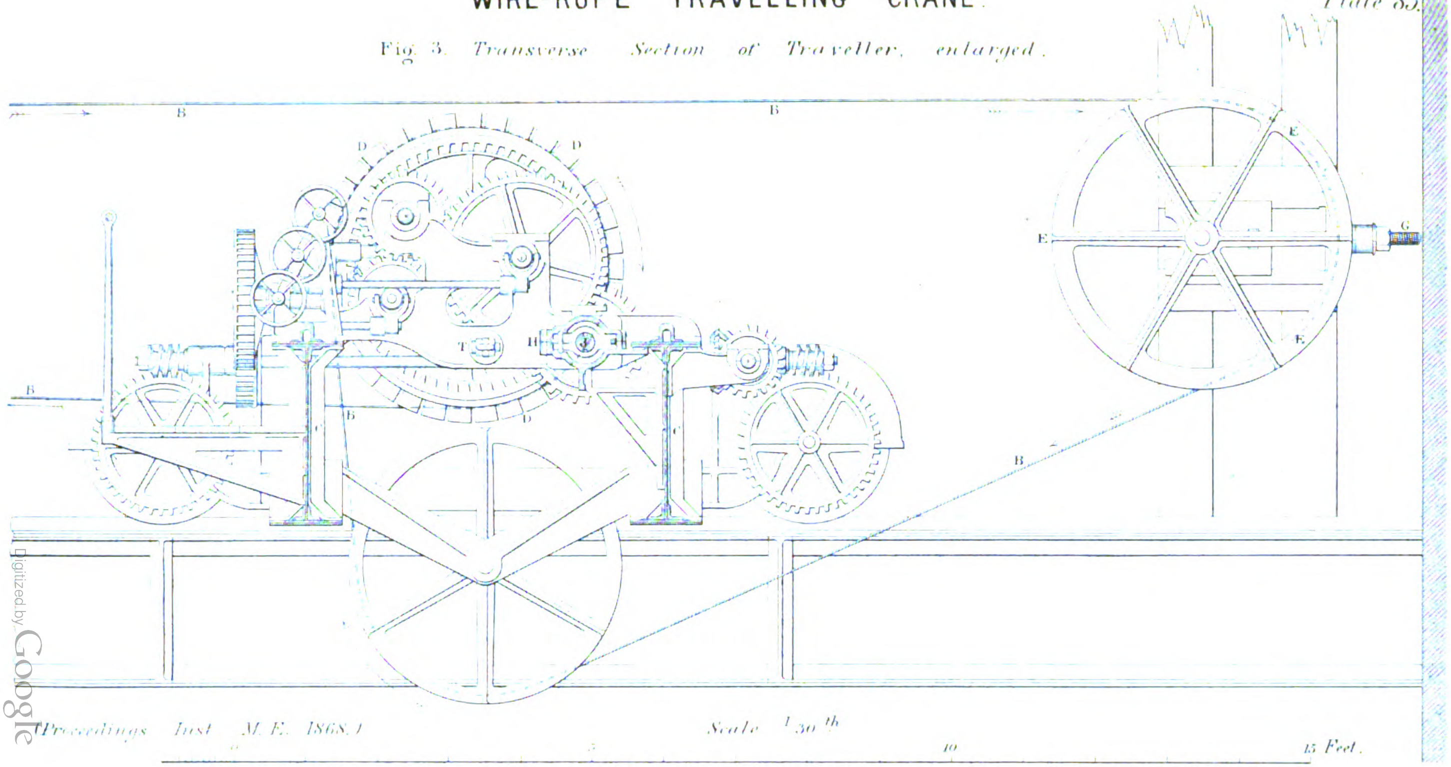
Fig. 2. *Plan of Traveller.*



(Proceedings Inst. M.E. 1868.)

WIRE-ROPE TRAVELLING CRANE.

Fig. 3. Transverse Section of Traveller, enlarged.

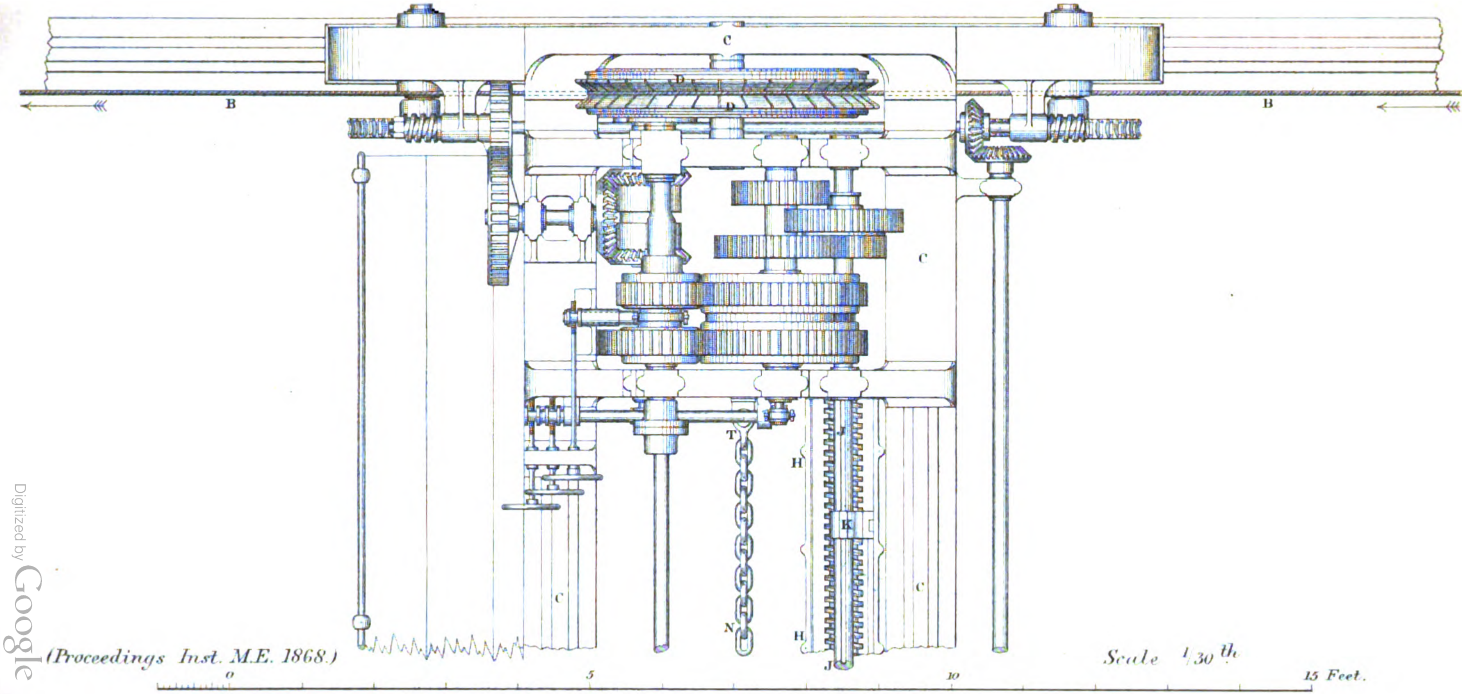


(Proceedings Inst. M. E. 1868.)

Scale 1/30th

WIRE-ROPE TRAVELLING CRANE.

Fig. 4. *Plan of end of Traveller, enlarged.*



(Proceedings Inst. M.E. 1868.)

WIRE-ROPE TRAVELLING CRANE.

Fig. 5. *Plan of Hoisting Screw and Screwed Barrel.*

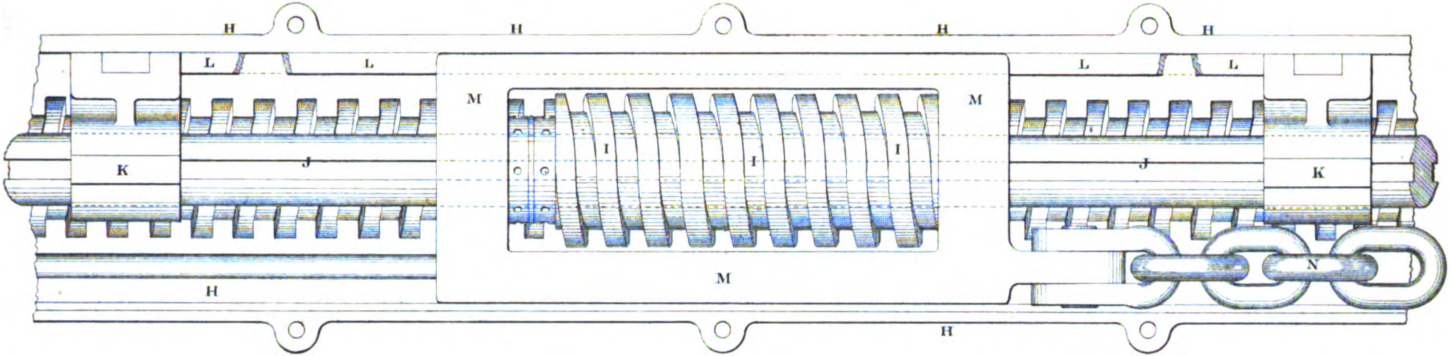


Fig. 6. *Transverse Section of Screwed Barrel.*

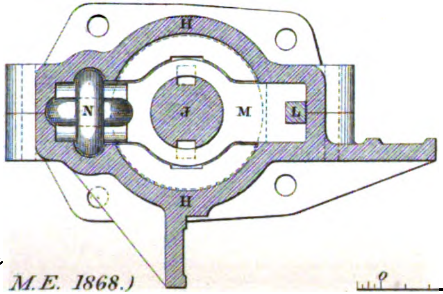
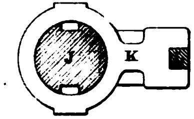


Fig. 7. *Brass Step of Driving Shaft.*



Scale $1/8$ th

(Proceedings Inst. M.E. 1868.)

Fig. 8. *Elevation of Cross Traversing Carriage on Traveller.*

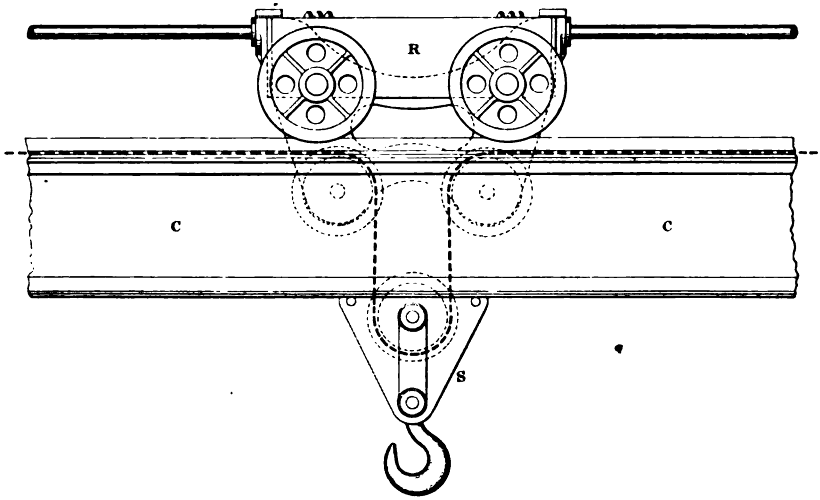
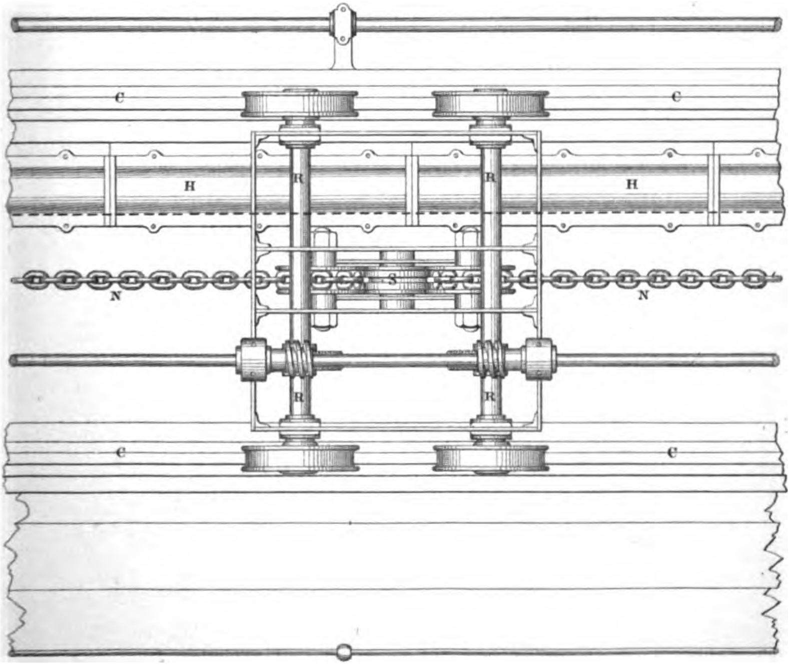


Fig. 9. *Plan of Cross Traversing Carriage.*

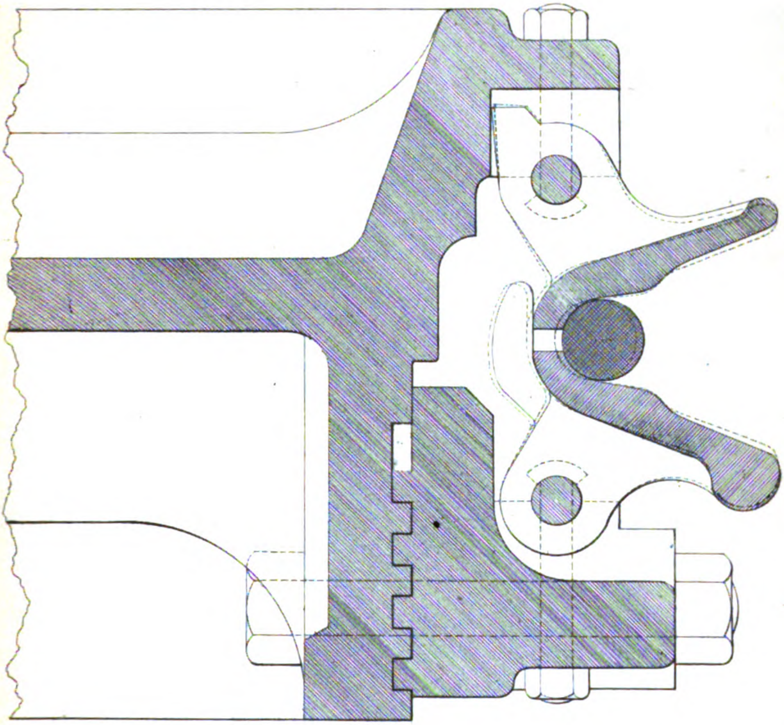


(Proceedings Inst. M. E. 1868.) *Scale 1/30th*

0 1 2 3 4 5 6 7 8 *Feet.*

WIRE-ROPE TRAVELLING CRANE. *Plate 87.*

Fig. 10. *Section of Rim of Clip Pulley.*



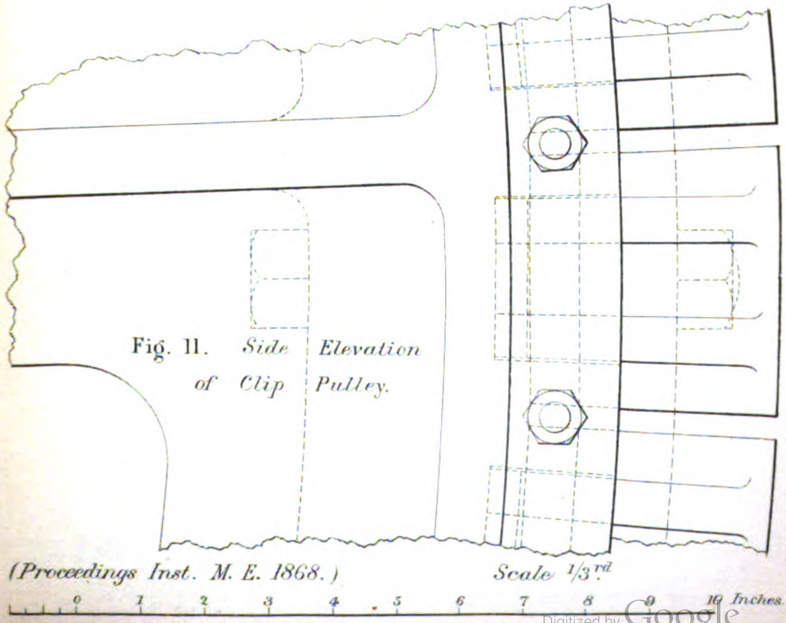


Fig. 11. *Side Elevation of Clip Pulley.*

(Proceedings Inst. M. E. 1868.)

Scale 1/3rd

CORLISS ENGINE.

Plate 88

Fig. 1.

Watt's Liberating Gear.

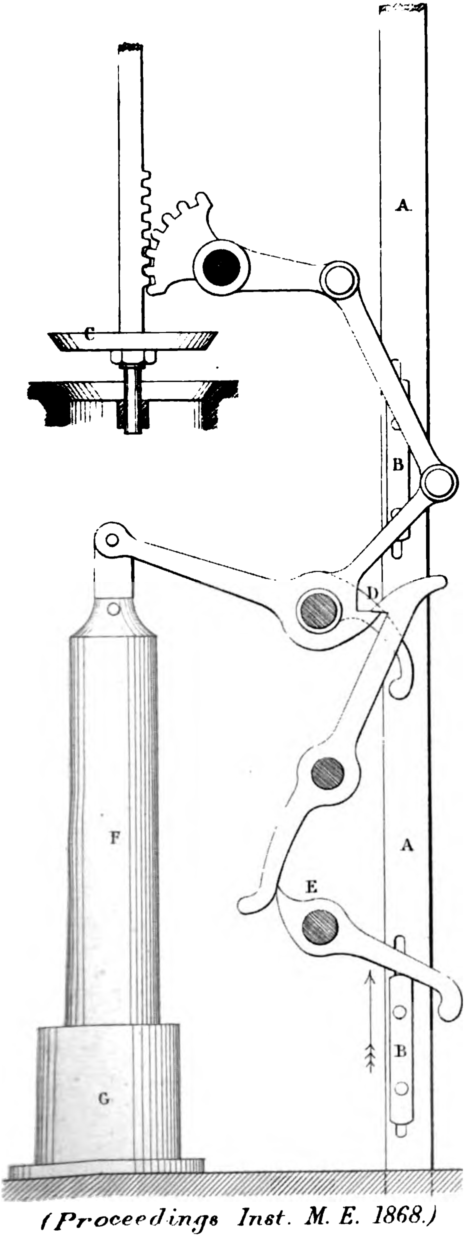
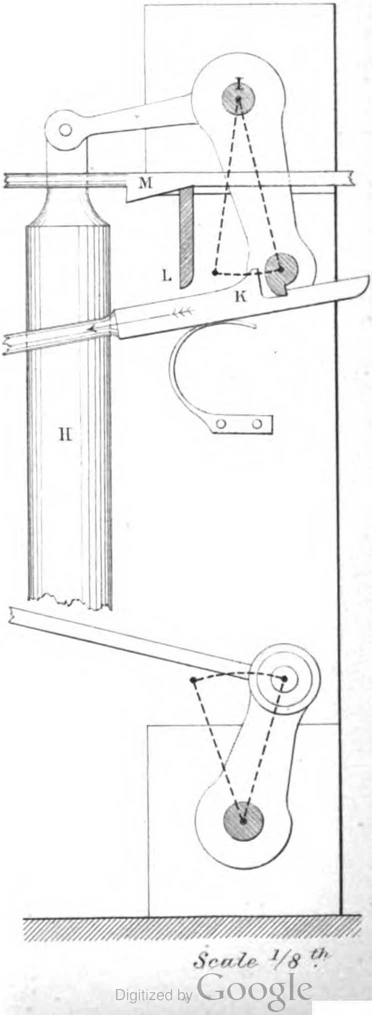


Fig. 2.

Corliss

Original Liberating Gear.



(Proceedings Inst. M. E. 1868.)

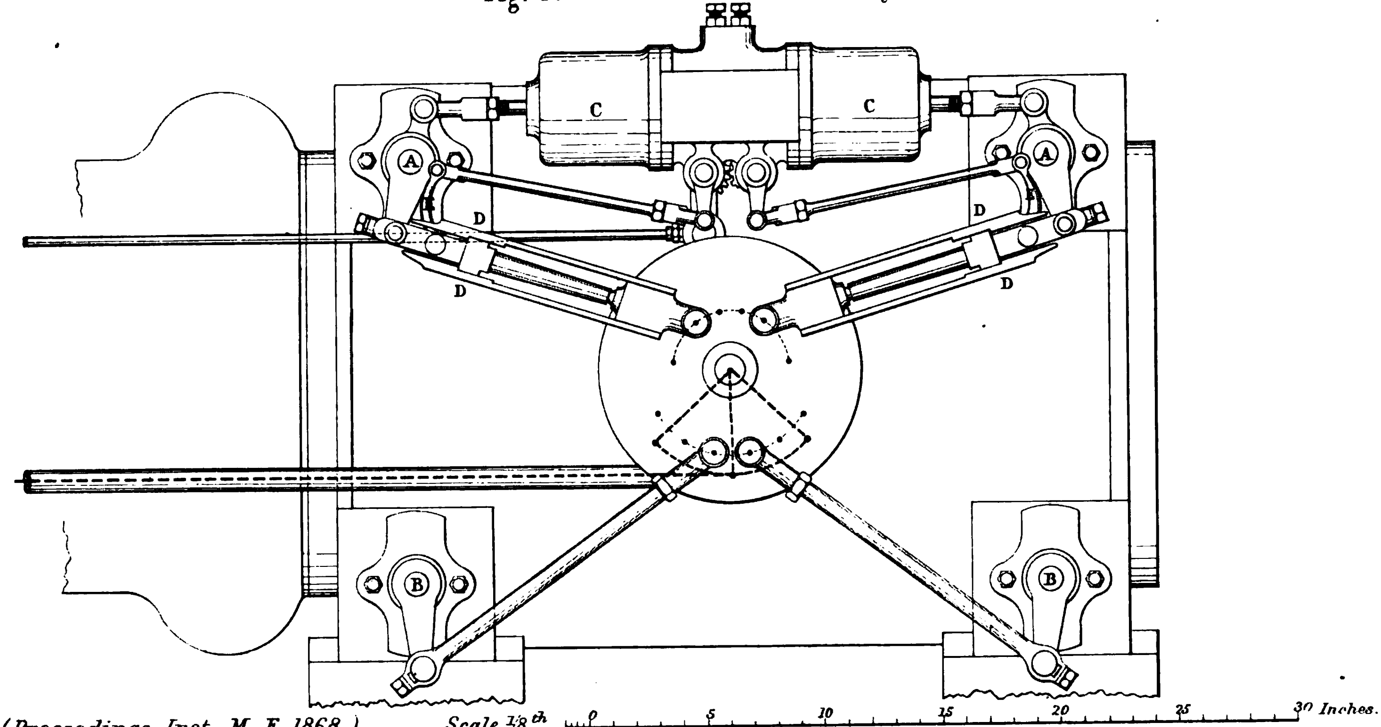
Scale 1/8th.

Plate 89.

CORLISS ENGINE.

Woolwich.

Fig. 3. *Side Elevation of Cylinder.*



(Proceedings Inst. M. E. 1868.)

Scale 1/8th.

CORLISS ENGINE.

Woolwich.

Fig. 4. Transverse Section of Cylinder.

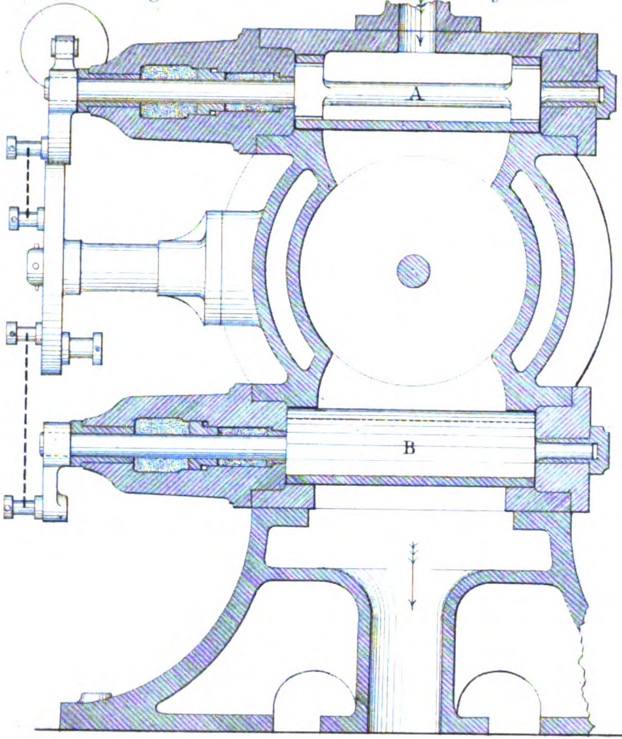
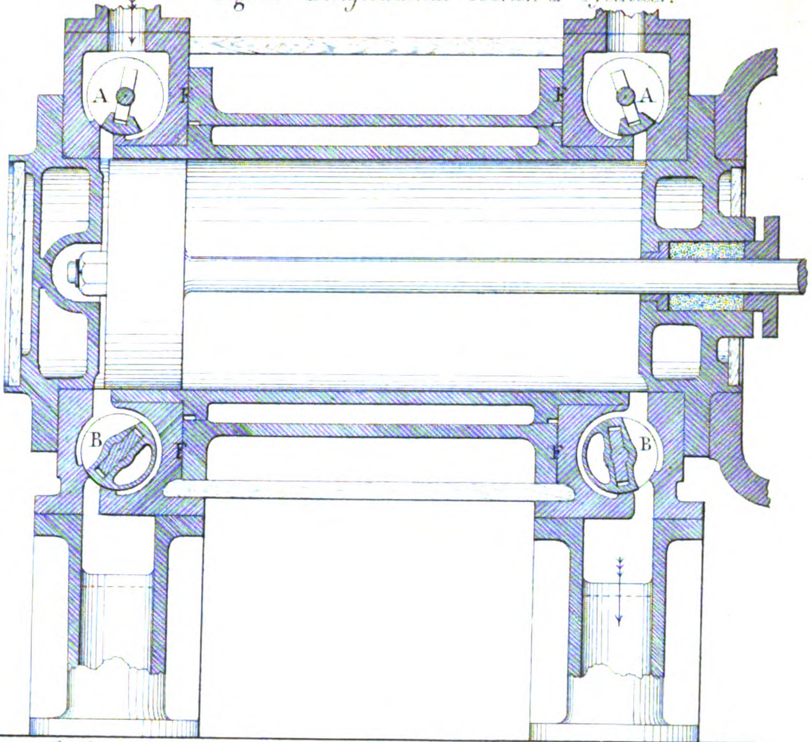


Fig. 5. Longitudinal Section of Cylinder.



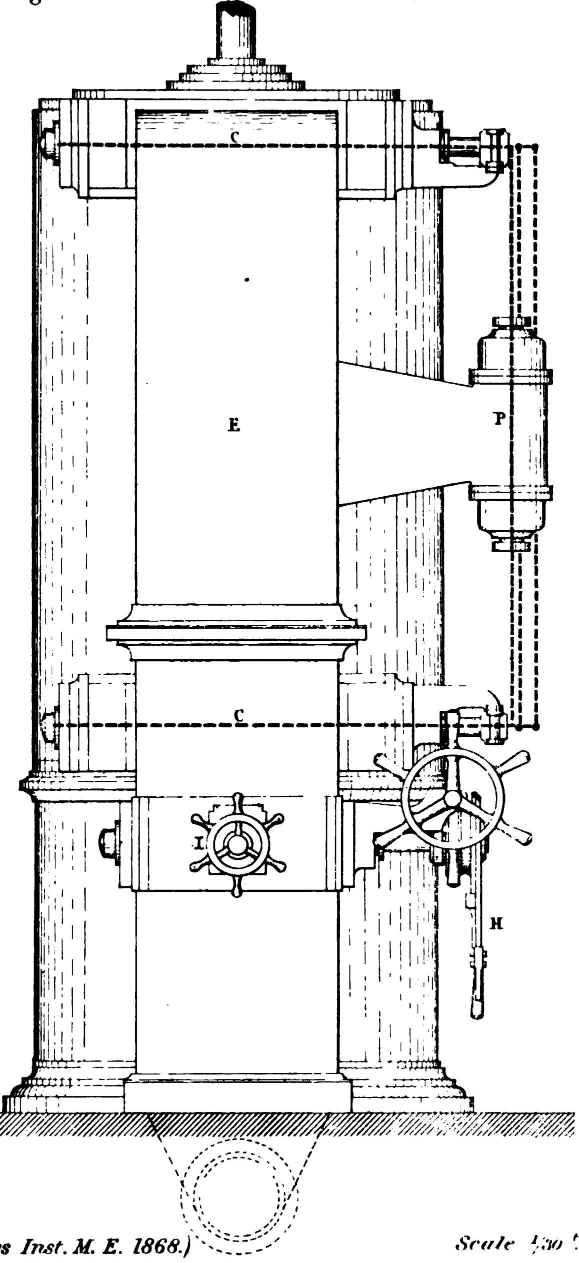
(Proceedings Inst. M. E. 1868.)

Scale 1/10th 0 5 10 15 20 25 30 Inches.

CORLISS ENGINE.

Saltaire.

Fig. 6. *Front Elevation of Cylinder.*



(Proceedings Inst. M. E. 1868.)

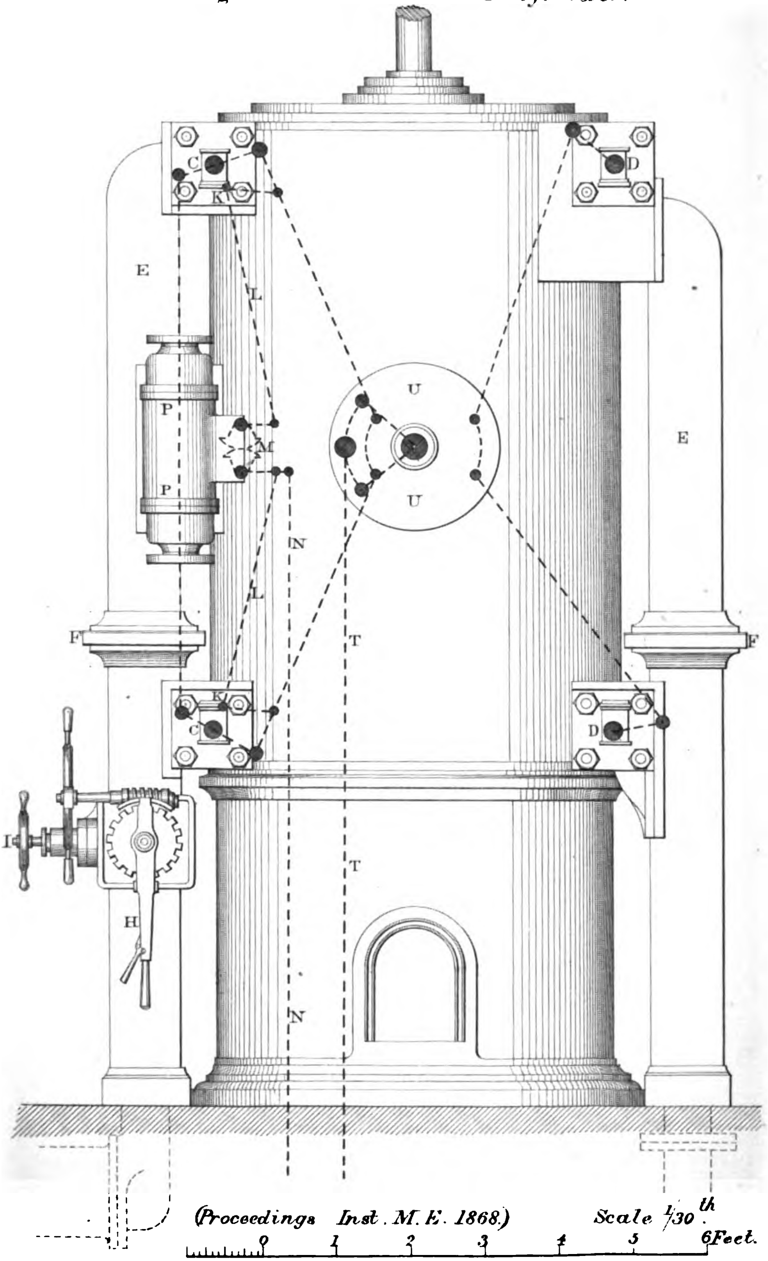
Scale 1/30th

CORLISS ENGINE.

Plate 92.

Saltaire.

Fig. 7. *Side Elevation of Cylinder.*



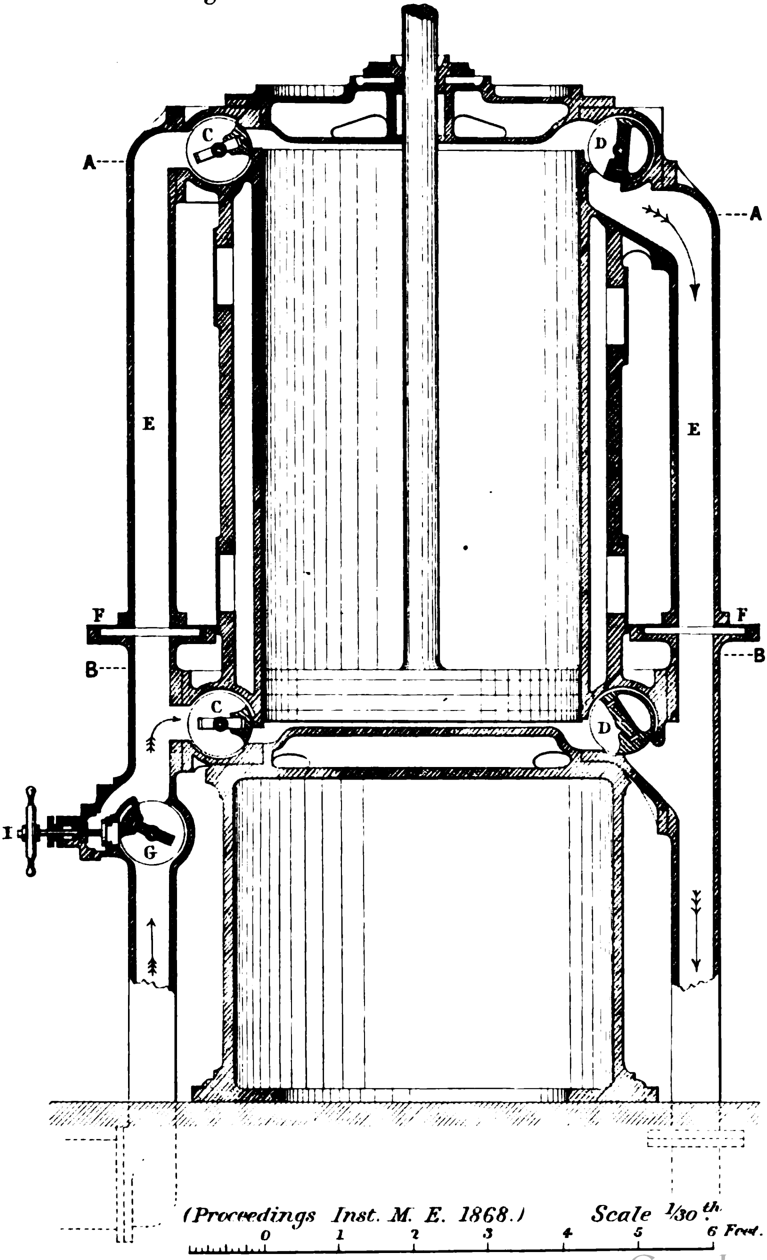
(Proceedings Inst. M. E. 1868.)

Scale 1/30th.

CORLISS ENGINE.

Saltaire.

Fig. 8. *Vertical Section of Cylinder.*



(Proceedings Inst. M. E. 1868.) *Scale 1/30th.*

CORLISS ENGINE.

Saltaire.

Fig. 9. *Plan of Cylinder at* **AA.** *(Fig 8.)*

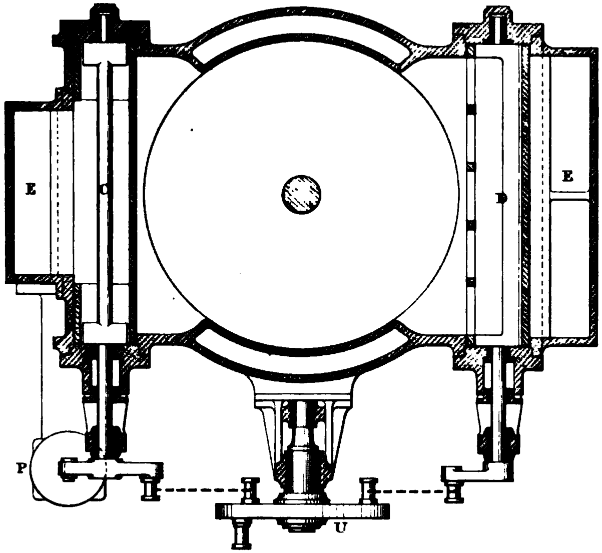
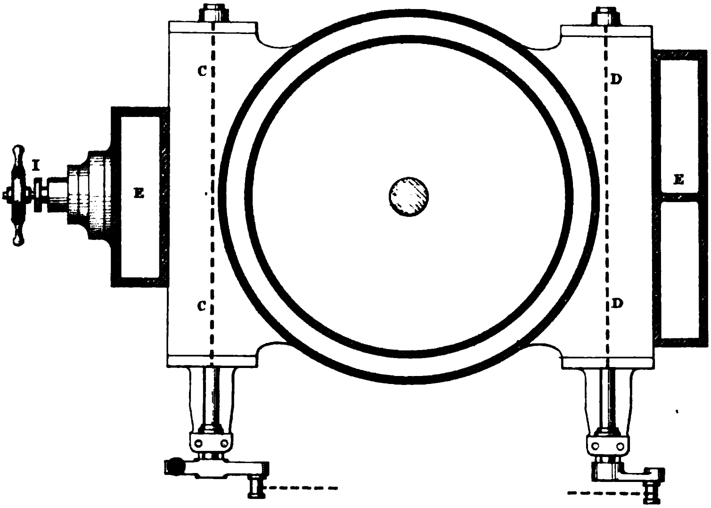


Fig. 10. *Plan of Cylinder at* **BB.** *(Fig. 8.)*



(Proceedings Inst. M. E. 1868.)

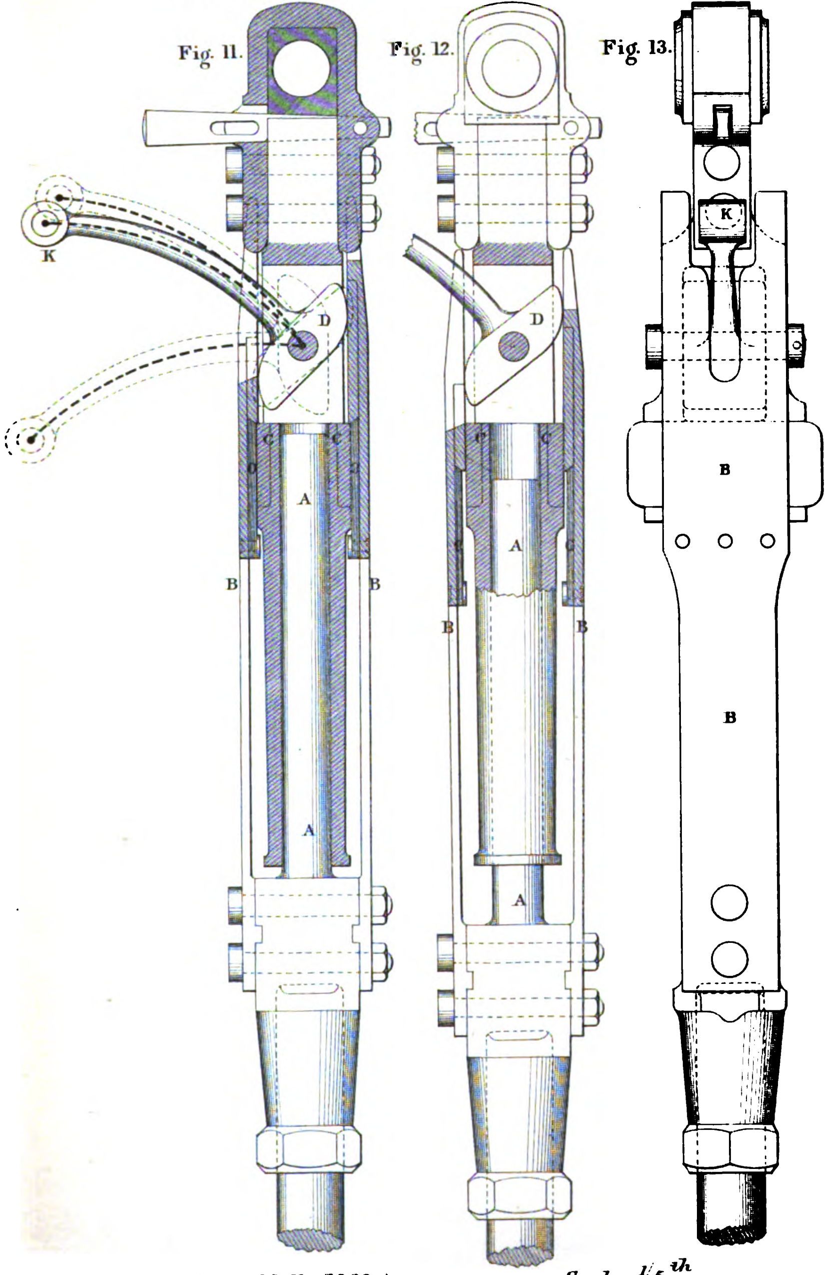
Scale 1/30th

CORLISS ENGINE. *Plate 95.*

Saltaire.

Liberating Gear for Steam Valves.

Fig. 11. Fig. 12. Fig. 13.



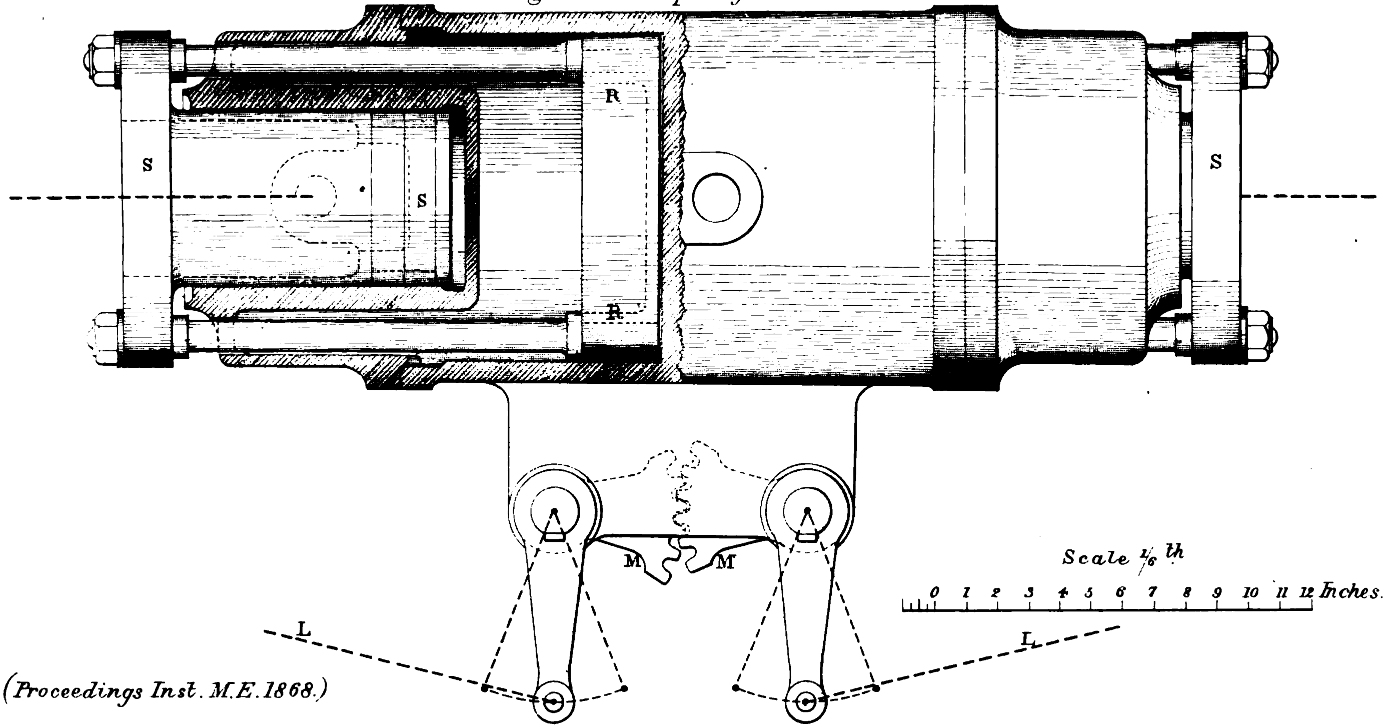
(Proceedings Inst. M. E. 1868.)

Scale 1/5 th

CORLISS ENGINE.

Saltaire.

Fig. 14. *Air-Spring Dash-Pot.*



(*Proceedings Inst. M.E. 1868.*)

CORLISS ENGINE. *Plate 97.*

Indicator Diagrams from Saltaire Engines.
Cylinder 50 ins. diamr., 7 ft. stroke.
30 Revolutions per minute.
Speed of Piston 420 feet per minute.

Fig. 15. *Steam cut off at 25 and 15 per cent.*

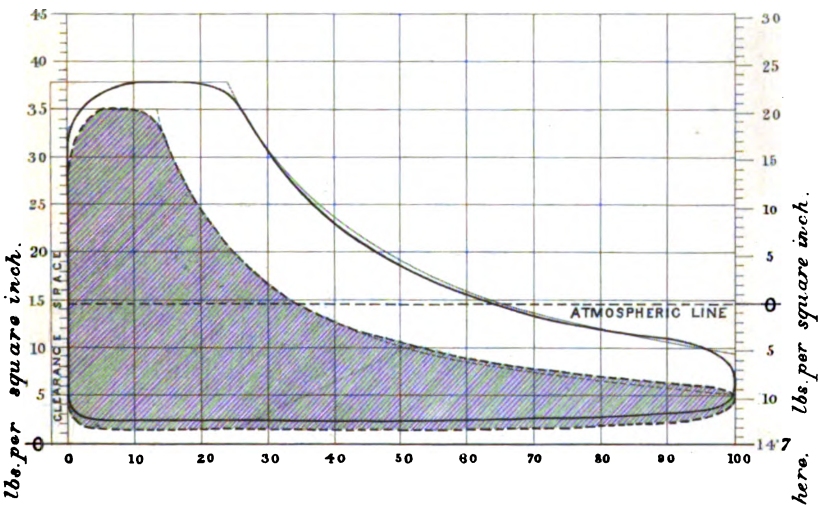
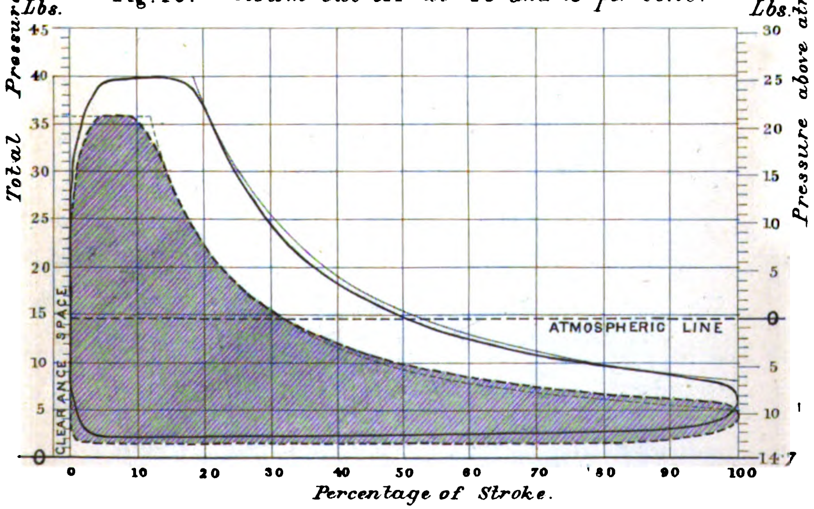


Fig. 16. *Steam cut off at 20 and 13 per cent.*

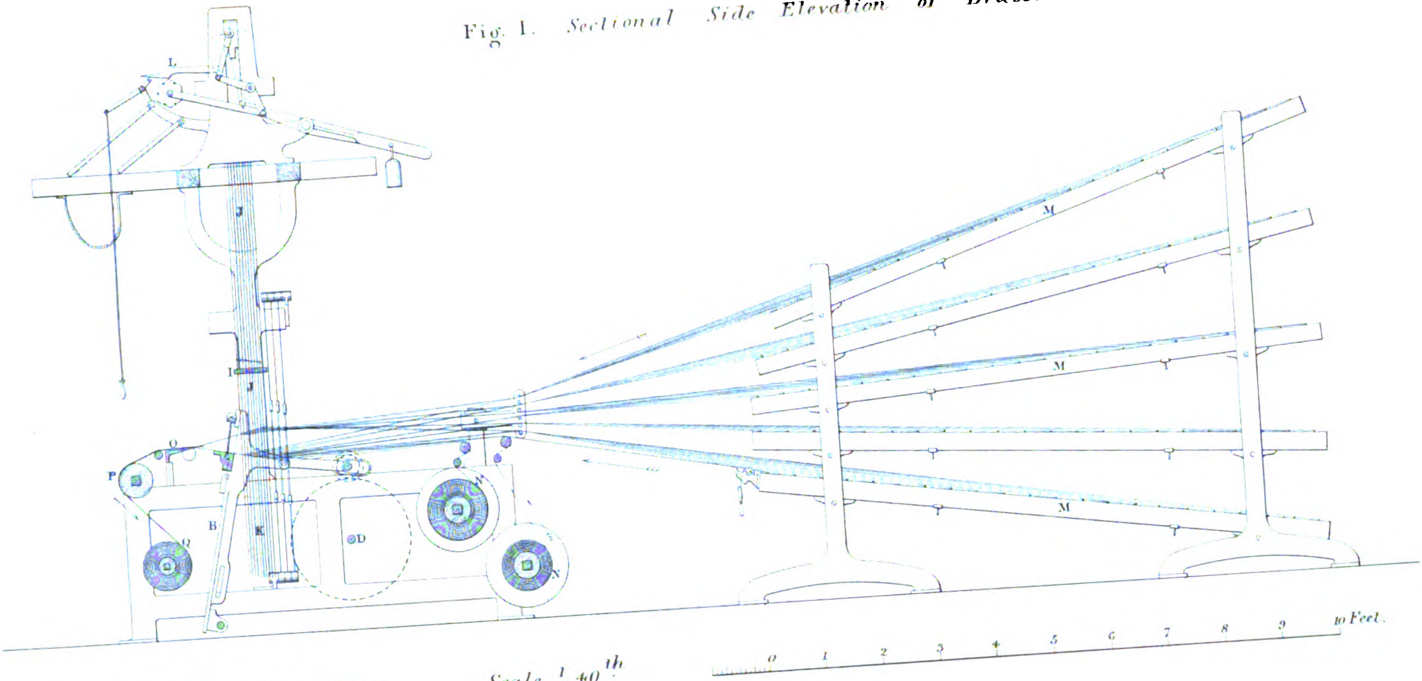


The fine lines show the theoretical true expansion curves.

(Proceedings Inst. M. E. 1868.)

BRUSSELS CARPET LOOM.

Fig. 1. *Sectional Side Elevation of Brussels Carpet Loom.*

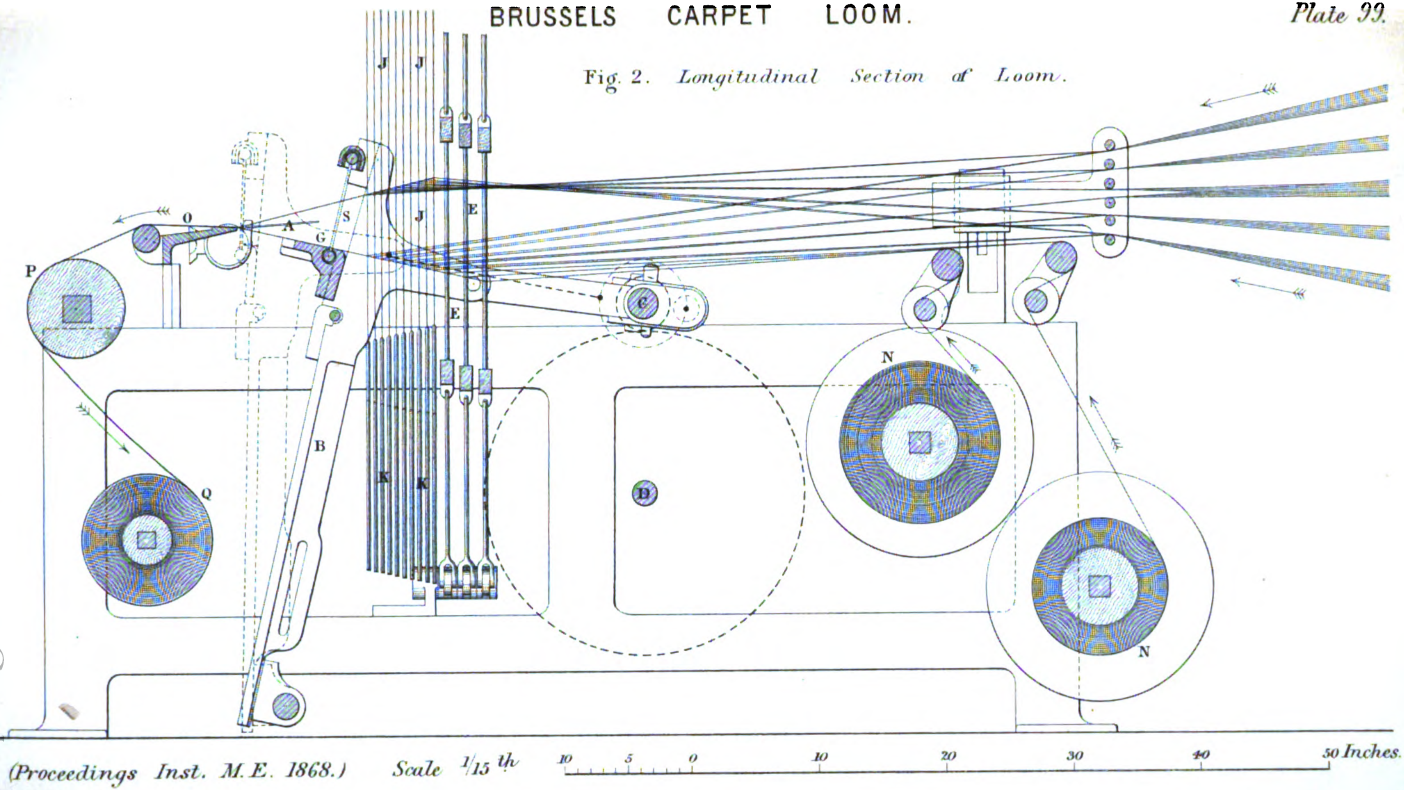


(Proceedings Inst. M. E. 1868.)

Scale 1/40th.

BRUSSELS CARPET LOOM.

Fig. 2. *Longitudinal Section of Loom.*



Scale 1/15 th

(Proceedings Inst. M.E. 1868.)

BRUSSELS CARPET LOOM.

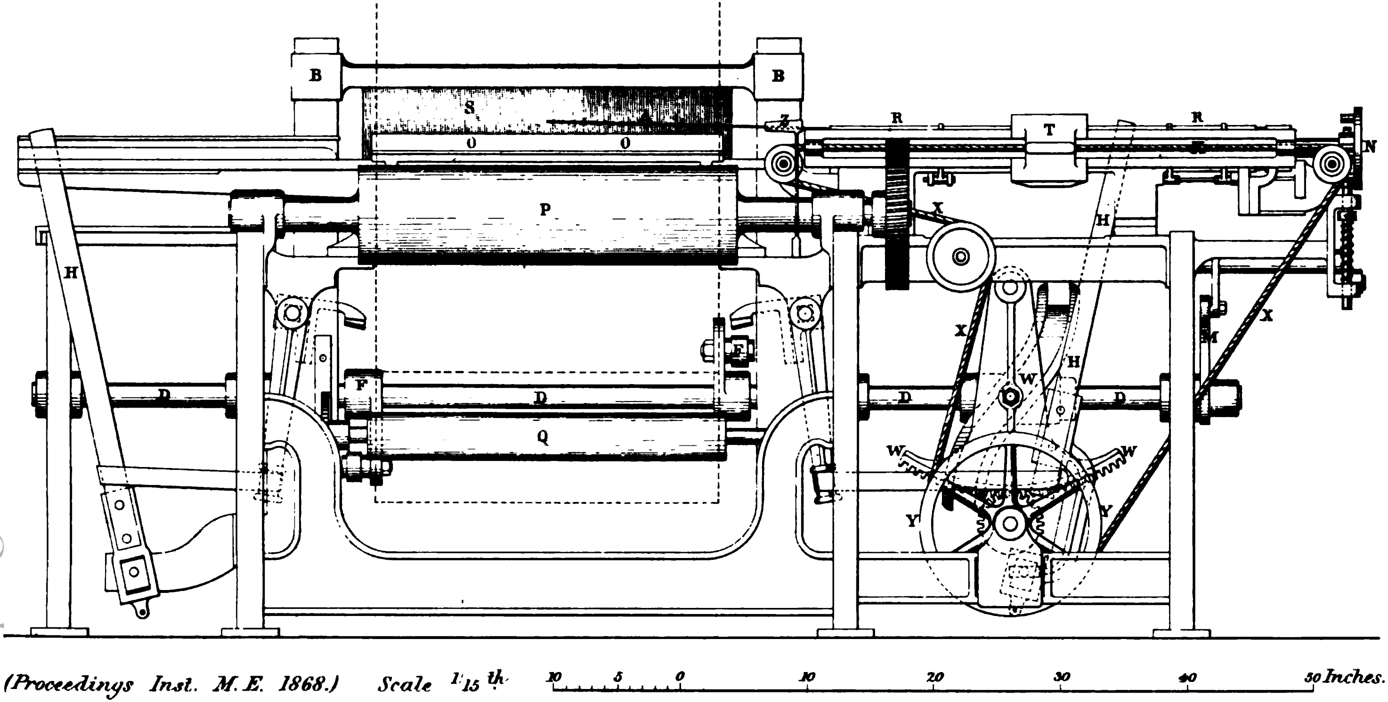


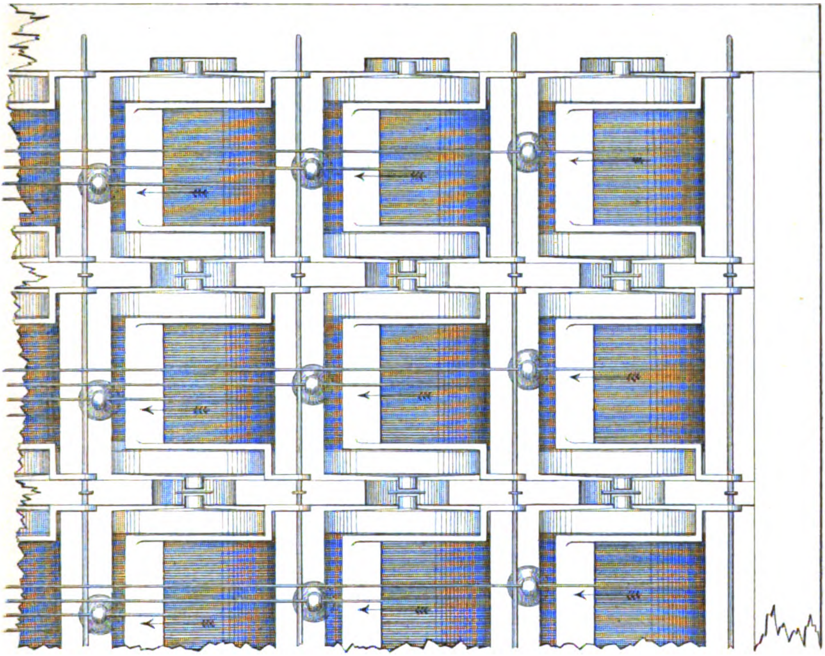
Fig. 3. *Front Elevation of Loom.*

(Proceedings Inst. M. E. 1868.) *Scale* 1/15th

BRUSSELS CARPET LOOM.

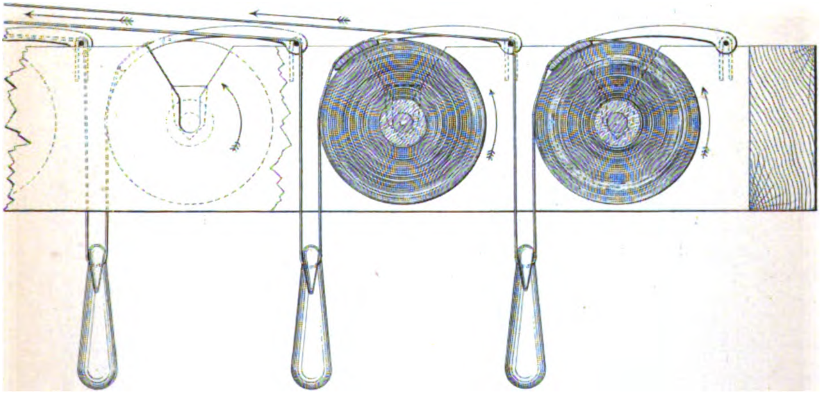
Plate 101.

Fig. 4. *Plan of Creel Frame.*



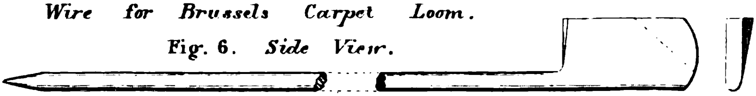
Scale 1/4th 0 5 10 *Inches.*

Fig. 5. *Side Elevation of Creel Frame.*



Wire for Brussels Carpet Loom.

Fig. 6. *Side View.*



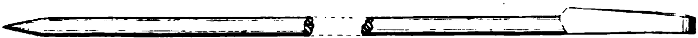


Fig. 7. *Edge View.* *Full size.*

(Proceedings Inst. M.E. 1868.)

BRUSSELS CARPET LOOM.

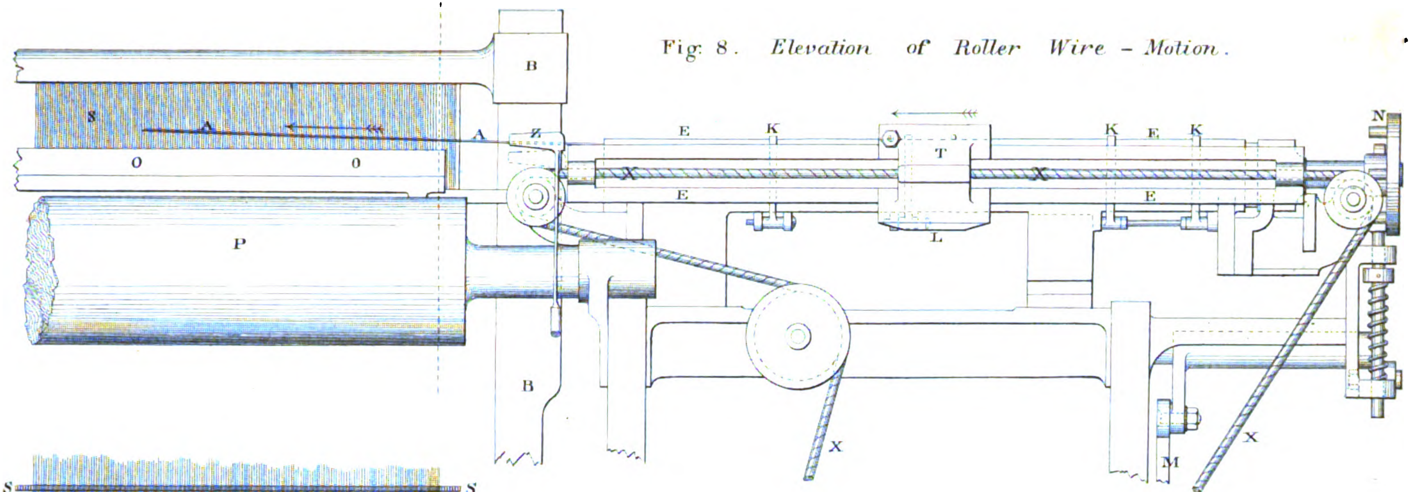


Fig. 8. Elevation of Roller Wire-Motion.

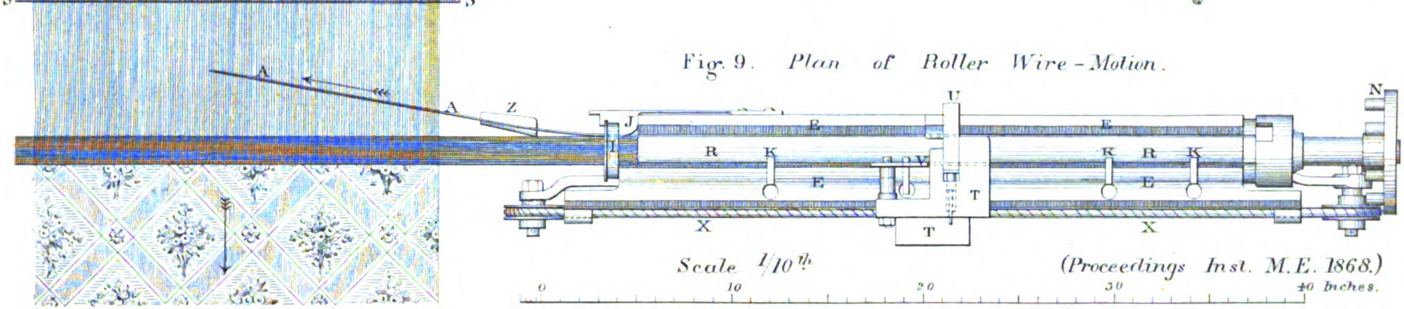
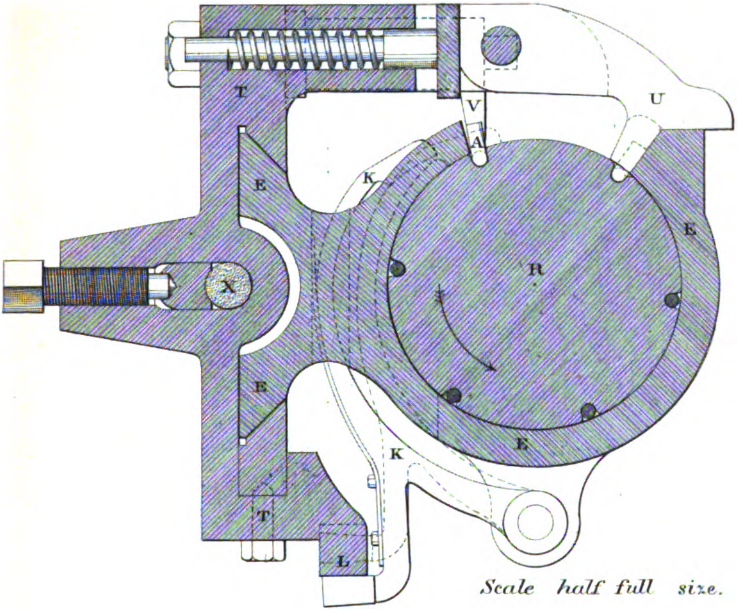


Fig. 9. Plan of Roller Wire-Motion.

Scale 1/10th

(Proceedings Inst. M.E. 1868.)

Fig. 10. *Transverse Section of Roller Wire-Motion. Scale 1/2.*



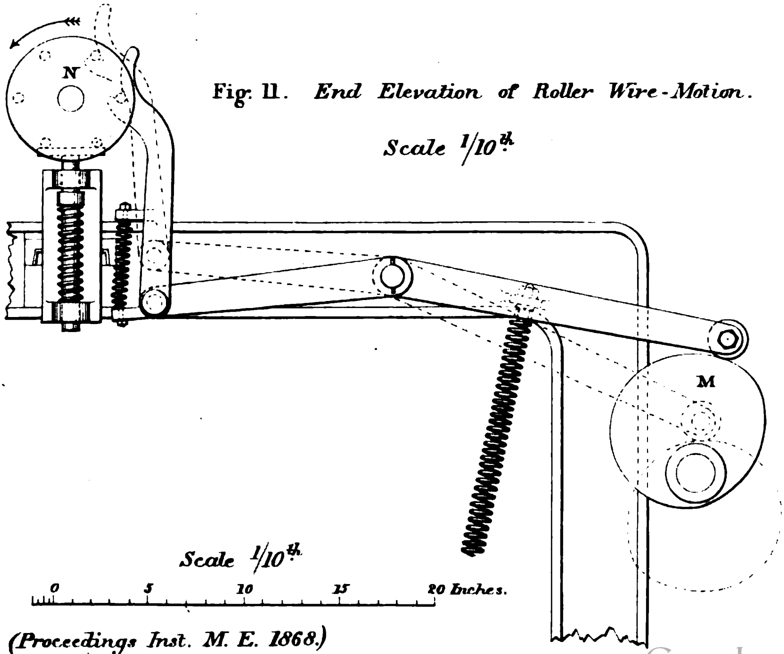


Fig. 11. *End Elevation of Roller Wire-Motion.*

Scale 1/10th

(Proceedings Inst. M. E. 1868.)

BRUSSELS CARPET LOOM.

Diagrams of Longitudinal Sections of Warp-pile Carpets.

Fig. 12. *Tapestry Carpet.*

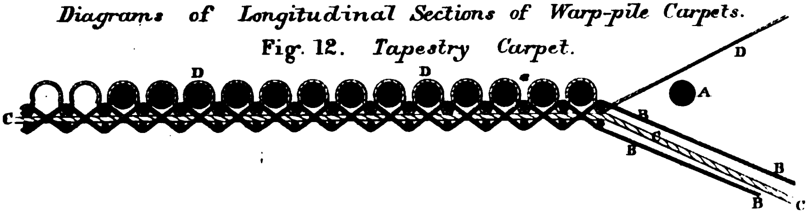


Fig. 13. *Brussels Carpet.*

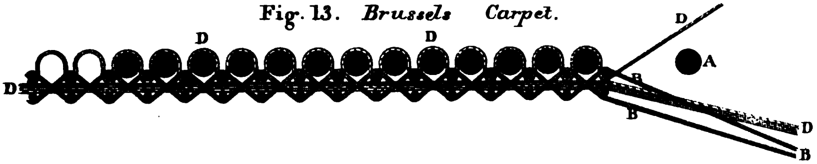


Fig. 14. *Velvet or Cut-pile Carpet.*

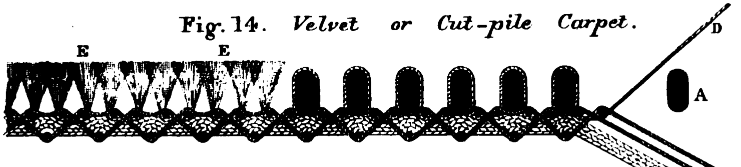
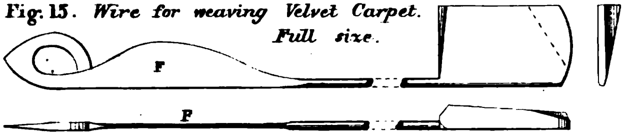


Fig. 15. *Wire for weaving Velvet Carpet. Full size.*



Diagrams of Sheds formed in weaving Brussels Carpet.

Scale 1/10th.

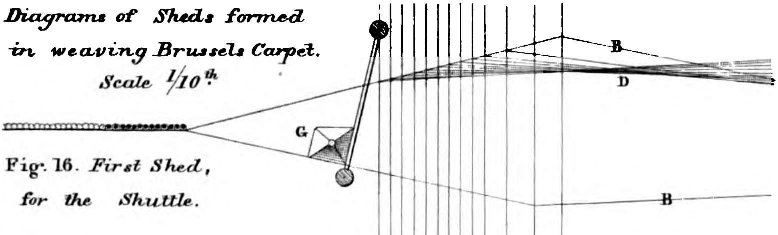


Fig. 16. *First Shed, for the Shuttle.*

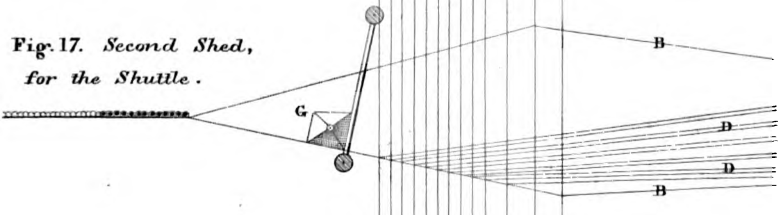


Fig. 17. *Second Shed, for the Shuttle.*

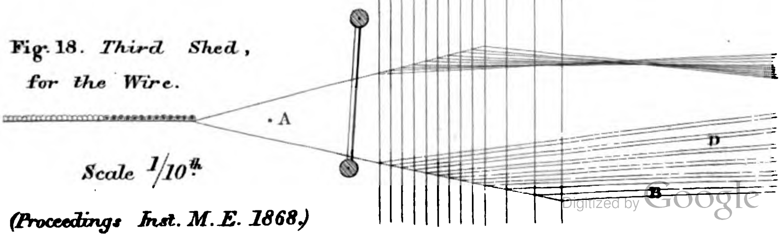


Fig. 18. *Third Shed, for the Wire.*

Scale 1/10th.

(Proceedings Inst. M.E. 1868.)

FRICTION COUPLING AND BREAK. *Plate 105.*

Fig. 1. *Model illustrating multiplication of frictional surfaces.*

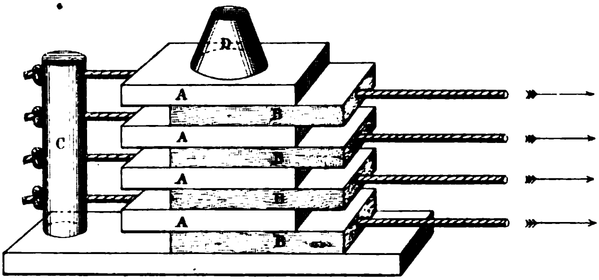
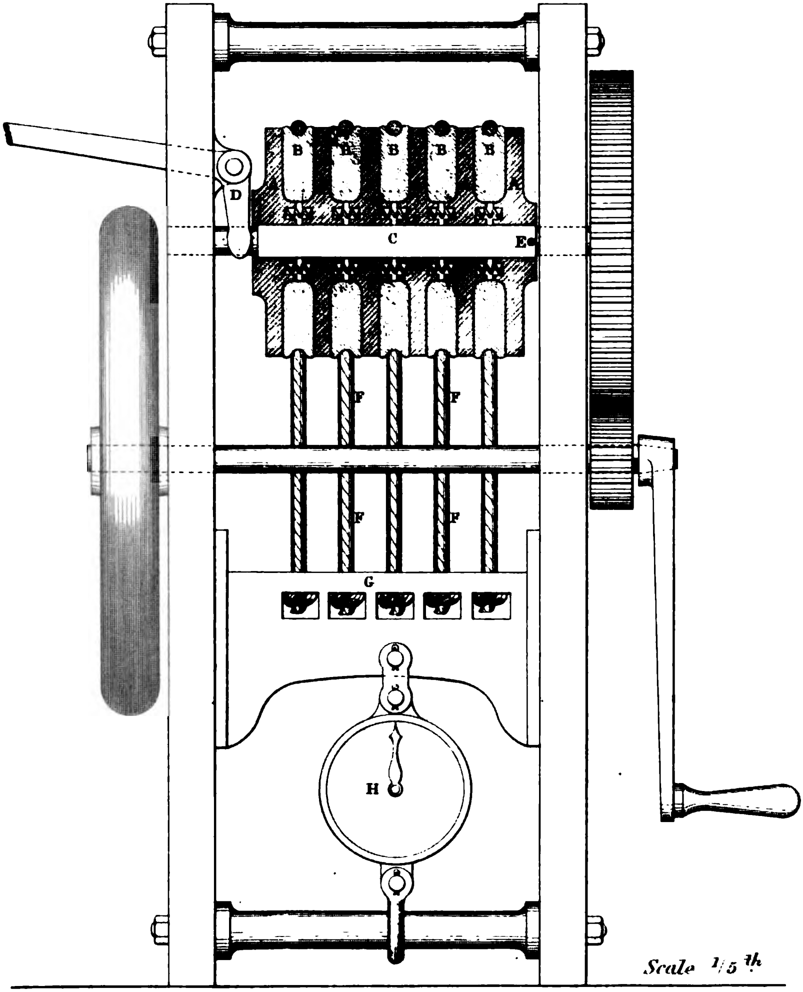


Fig. 2. *Experimental Disc Break.*



Scale 1/5th

FRICTION COUPLING AND BREAK. *Plate 106.*

Six-ton Hoisting Crab.

Fig. 3. *Longitudinal Section.*

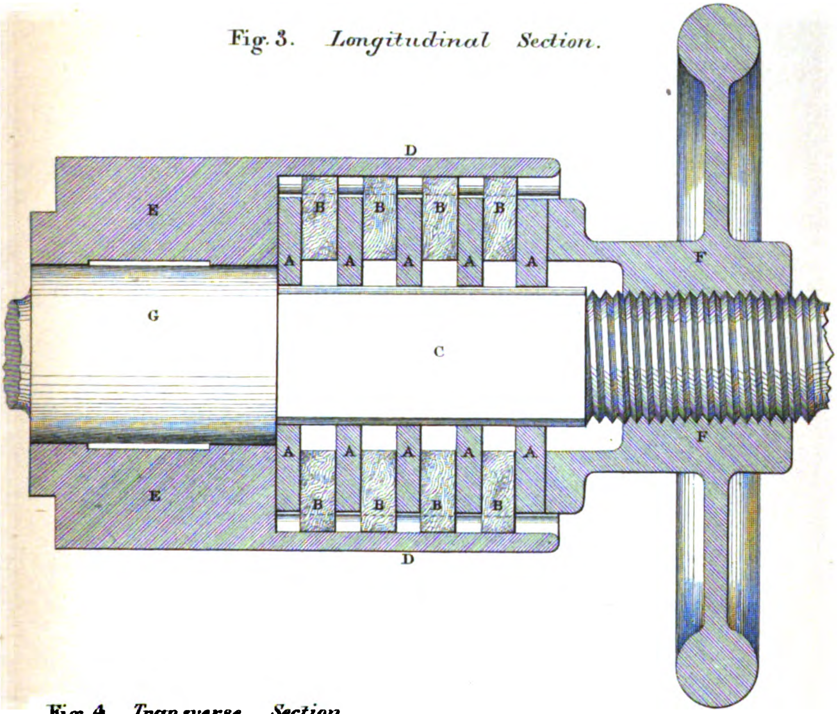


Fig. 4. *Transverse Section showing Wood Disc.*

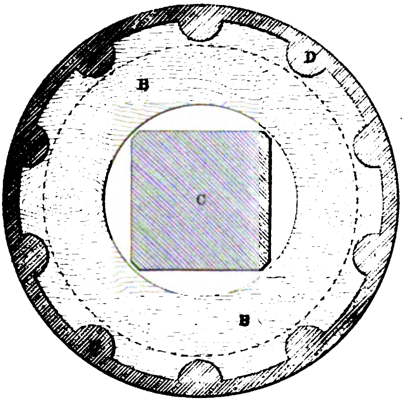
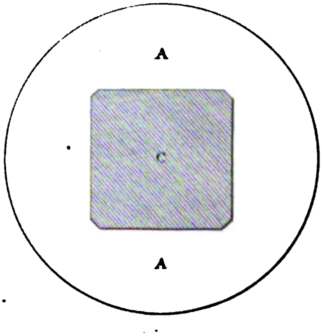


Fig. 5. *Transverse Section showing Iron Disc.*



(Proceedings Inst. M. E. 1868.)

Scale 1/3rd

Sack Hoist,

stopped by rope in lowering,

for quick lowering.

Fig. 6. *End Elevation.* *Scale 1/10th.*

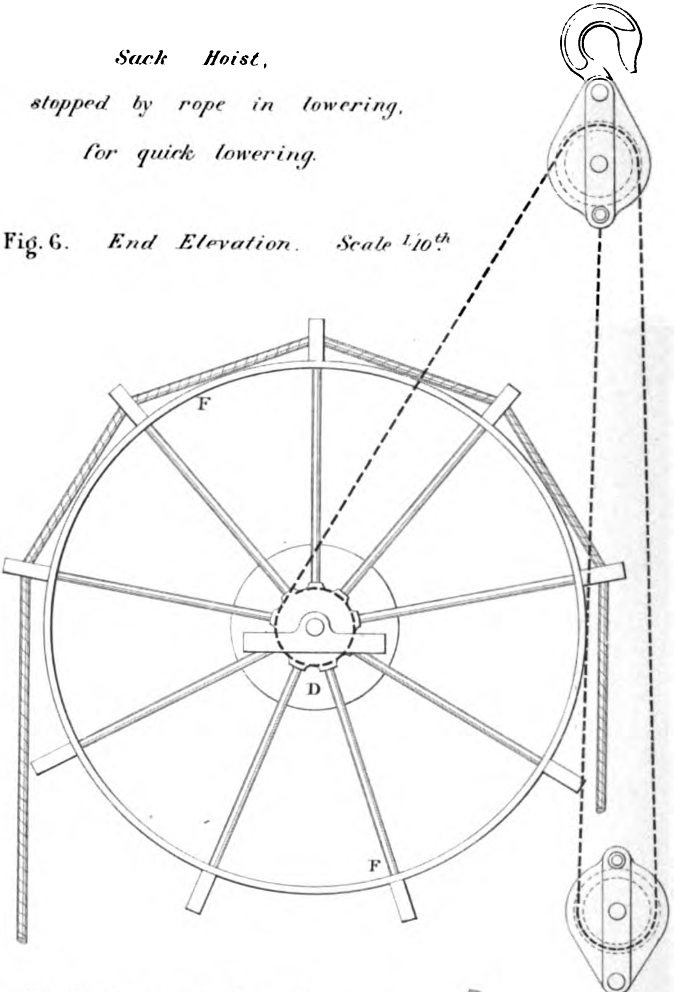
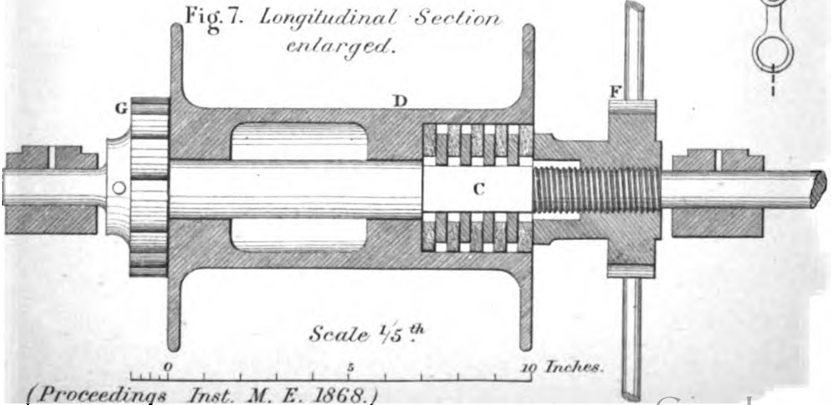


Fig. 7. *Longitudinal Section enlarged.*



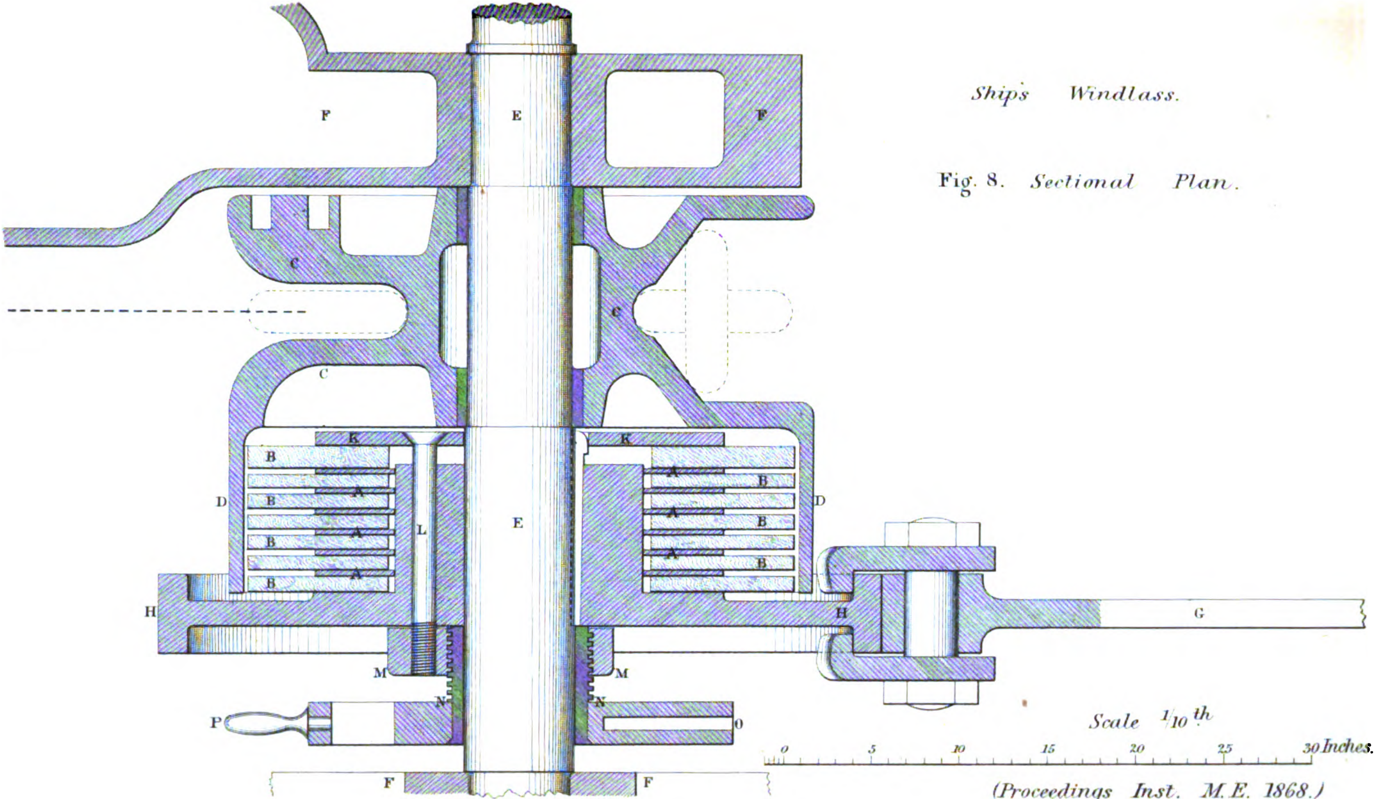
(Proceedings Inst. M. E. 1868.)

FRICTION COUPLING AND BREAK.

Plate 108.

Ships Windlass.

Fig. 8. *Sectional Plan.*



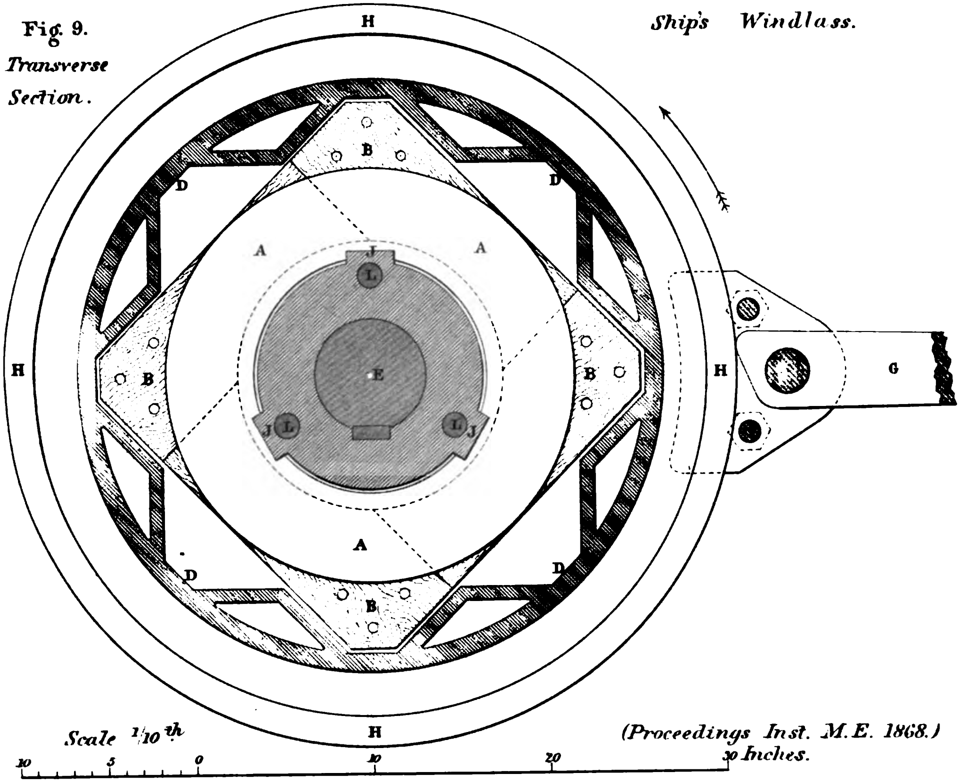
Scale ¹⁄₁₀th.

(Proceedings Inst. M.E. 1868.)

FRICTION COUPLING AND BREAK.

Ship's Windlass.

Fig. 9. *Transverse Section.*



(Proceedings Inst. M.E. 1868.)

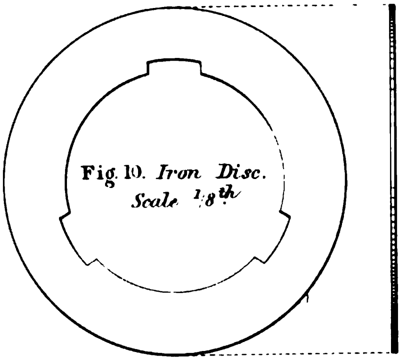


Fig. 10. *Iron Disc.* *Scale 1/8th.*

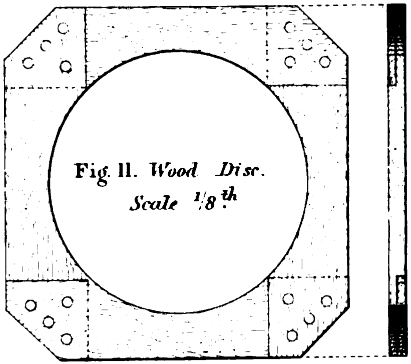


Fig. 11. *Wood Disc.* *Scale 1/8th.*

FRICTION COUPLING AND BREAK. *Plate 110.*

Shaft Coupling.

Fig. 12. *Longitudinal Section.*

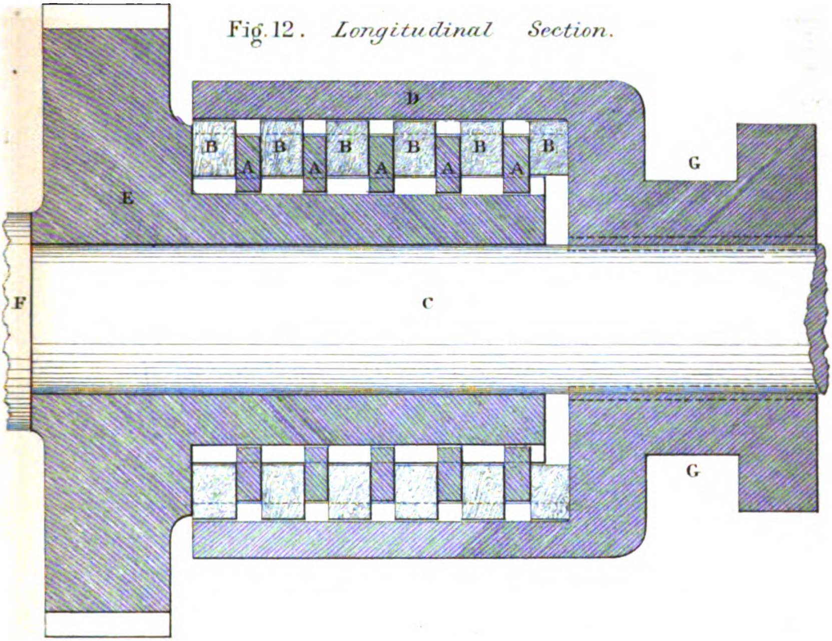


Fig. 13.
Transverse Section showing Iron Disc.

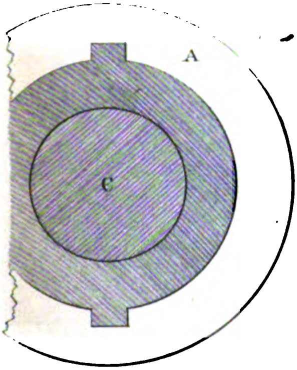
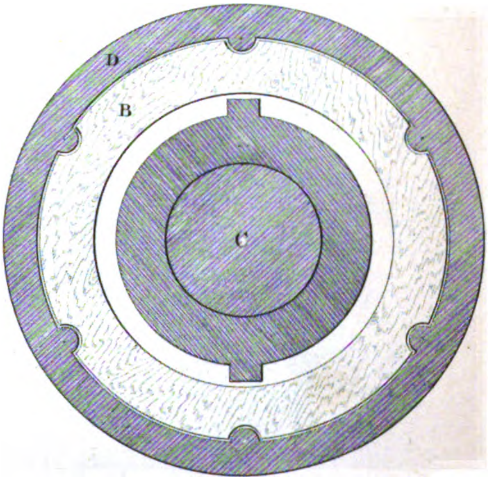


Fig. 14. *Transverse Section showing Wood Disc.*



Scale ¼th. 0 1 2 3 4 5 6 7 8 9 10 *Inches.*

(Proceedings Inst. M. E. 1868.)

Safety Clutch.

Fig. 15. *Longitudinal Section.*

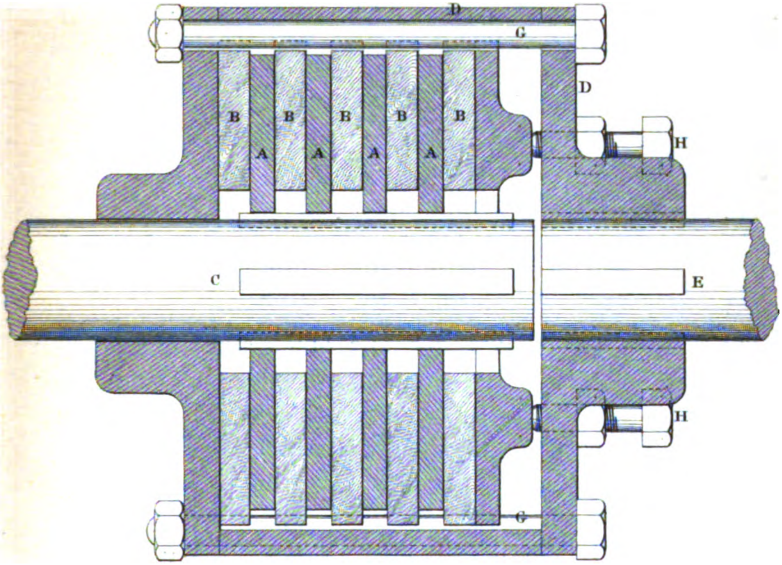
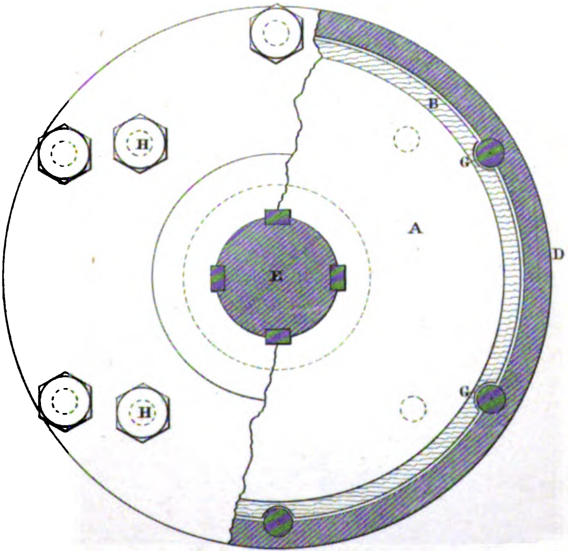


Fig. 16. *End Elevation and Transverse Section.*



(Proceedings Inst. M.E. 1868.)

Scale $1/4$ th

FRICTION COUPLING AND BREAK. *Plate 112.*

Self-engaging Shaft Coupling.

Fig. 17. *Longitudinal Section.*

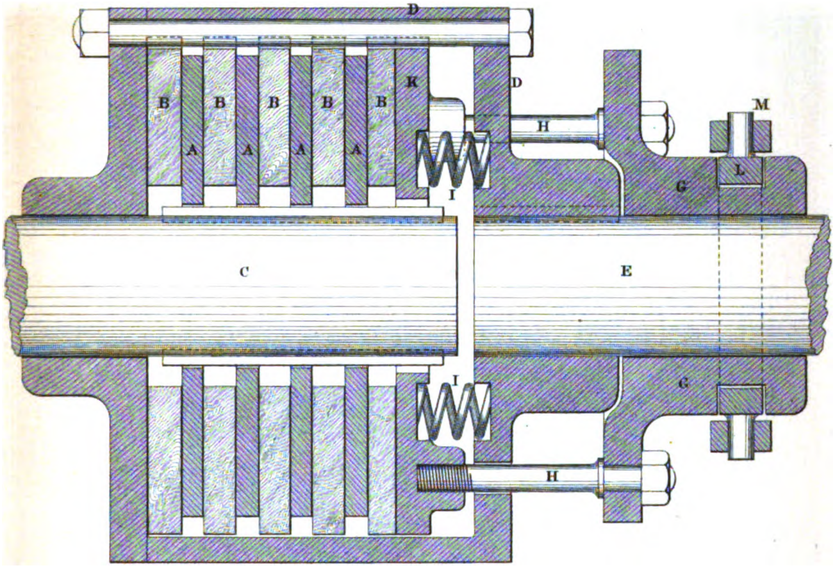
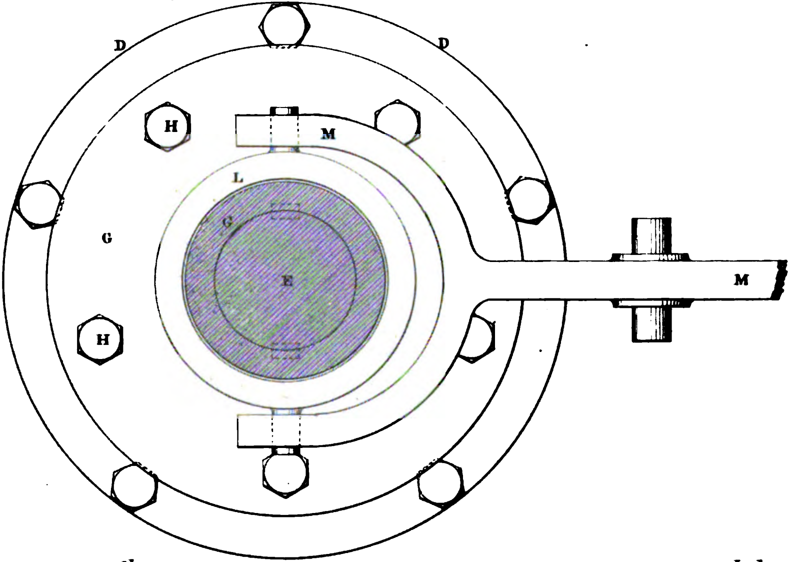


Fig. 18. *End Elevation.*

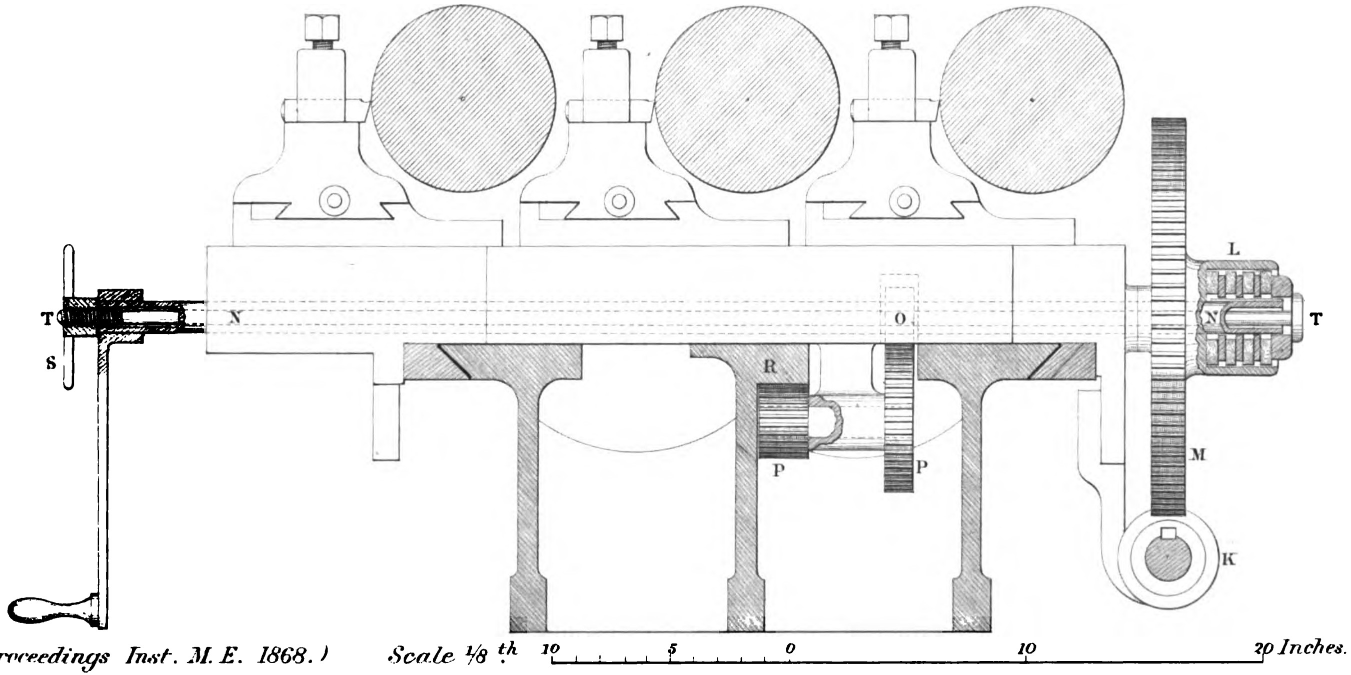


Scale 1/4 th 0 1 2 3 4 5 6 7 8 9 10 *Inches.*

(Proceedings Inst. M. E. 1868.)

FRICTION COUPLING AND BREAK.

Fig. 19. *Lathe Coupling.*



(Proceedings Inst. M. E. 1868.)

Scale 1/8 th

FRICTION COUPLING AND BREAK.

Safety Pinion.

Fig. 20. *Longitudinal Section.*

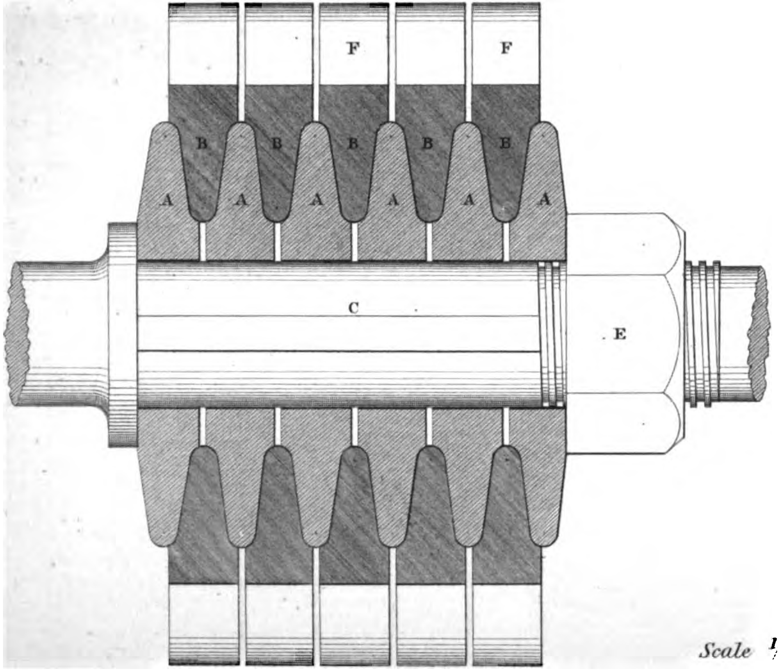
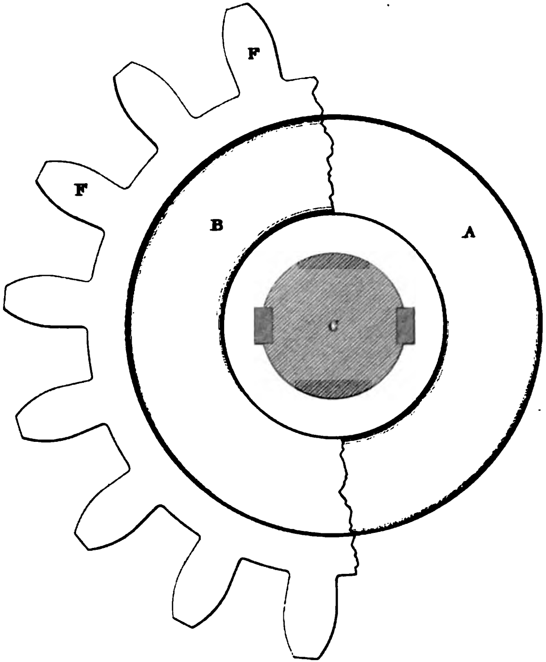


Fig. 21. *Transverse Section.*



Scale 1/5 th

0 5 10 15 20 *Inches.*

(Proceedings Inst. M. E. 1868.)

FRICTION COUPLING AND BREAK. *Plate 115.*

Sack Hoist.

lowered by rope continuously,
for slow lowering.

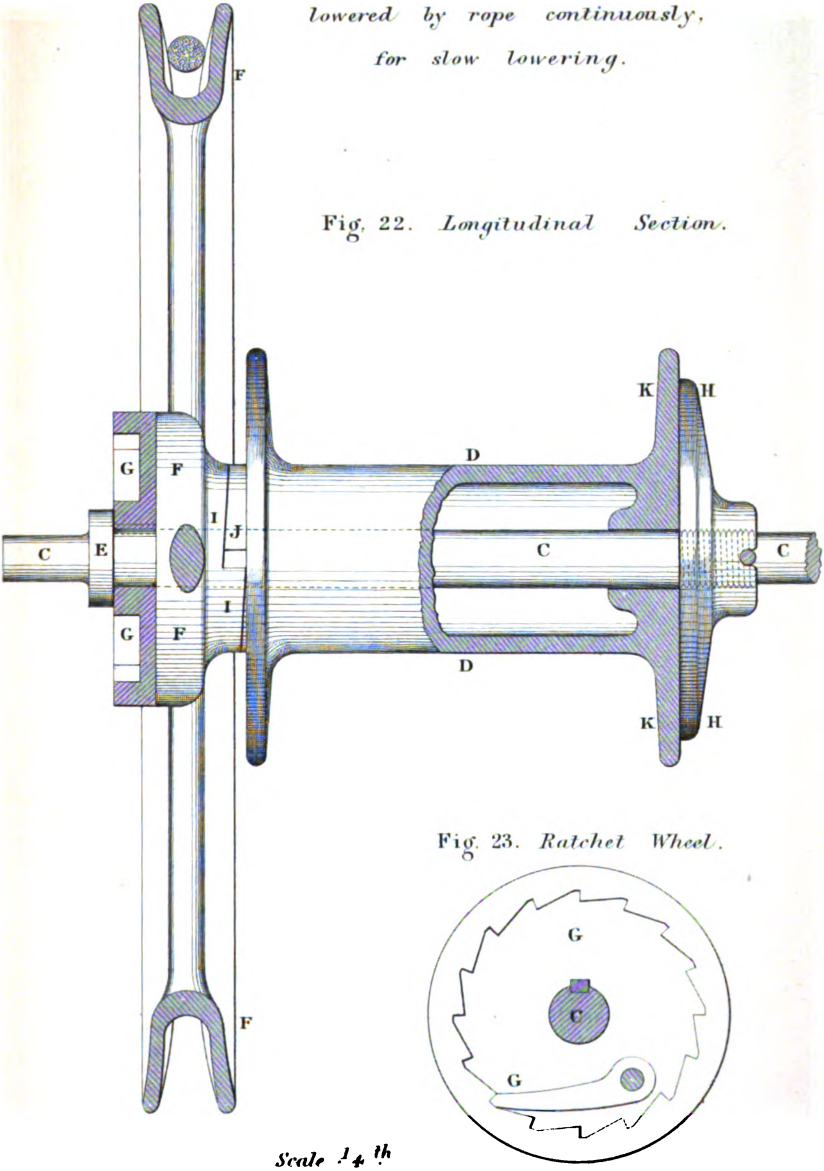
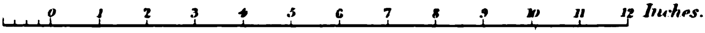


Fig. 22. *Longitudinal Section.*

Fig. 23. *Ratchet Wheel.*

Scale ¼th



(Proceedings Inst. M.E. 1868.)

FRICTION COUPLING AND BREAK.

Bracket Winch, lowered by handle continuously, for slow lowering.

Fig. 24. *End Elevation.*

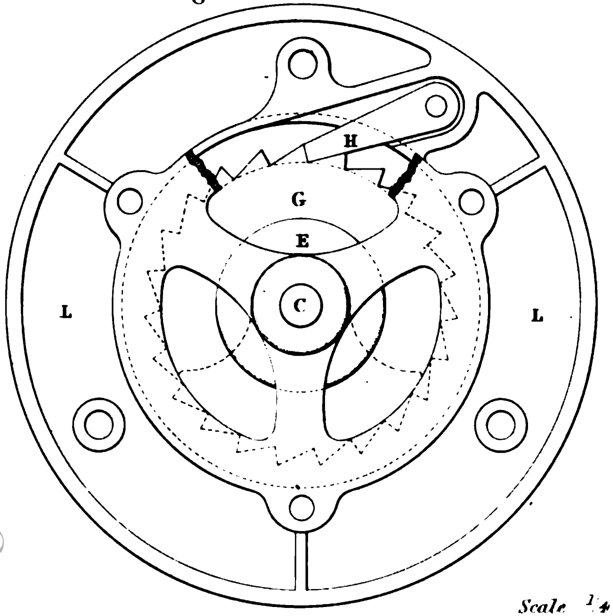
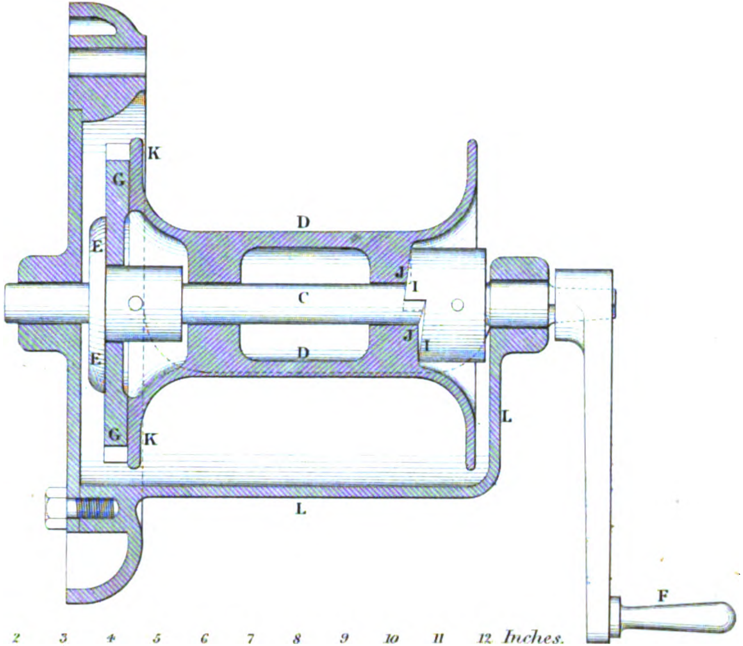


Fig. 25. *Longitudinal Section.*



Scale ¼th

0 1 2 3 4 5 6 7 8 9 10 11 12 *Inches.*

(Proceedings Inst. M.E. 1868.)

FRICTION COUPLING AND BREAK. *Plate 117.*

Fig. 26. *Hoisting Crab, lowered by handle continuously, for slow lowering.*

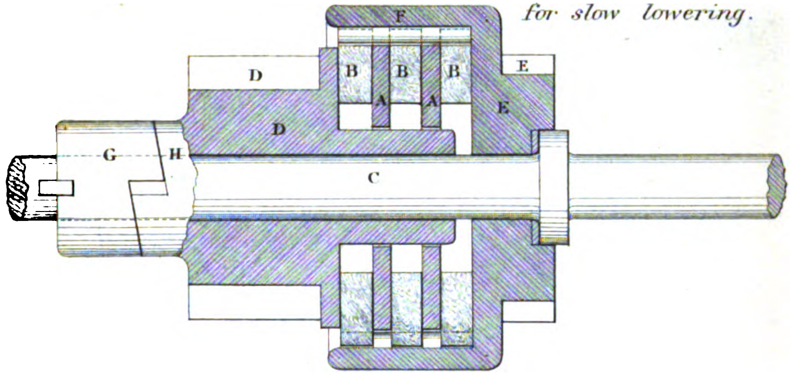


Fig. 27. *Hoisting Crab, stopped by handle in lowering, for quick lowering.*

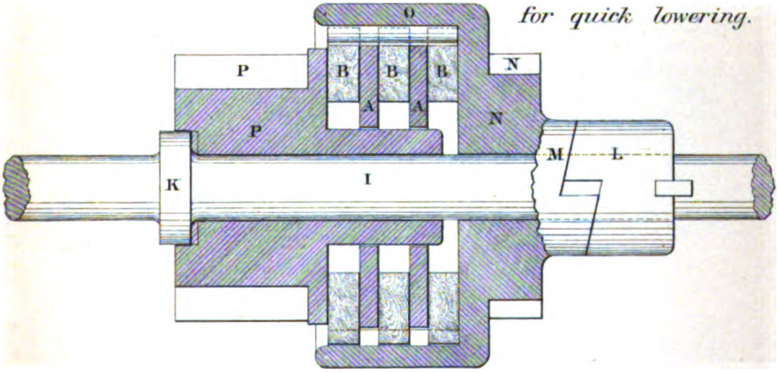
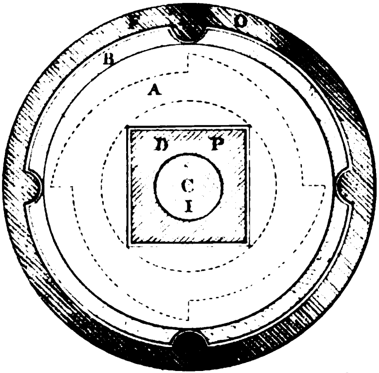


Fig. 28. *Transverse Section of both Crabs.*



(Proceedings Inst. M. E. 1868.) *Scale 1/3rd.*

0 1 2 3 4 5 6 7 8 9 10 *Inches.*

WHEEL MOULDING MACHINE. *Plate 118.*

Fig. 1. *End Elevation of Moulding Machine.*

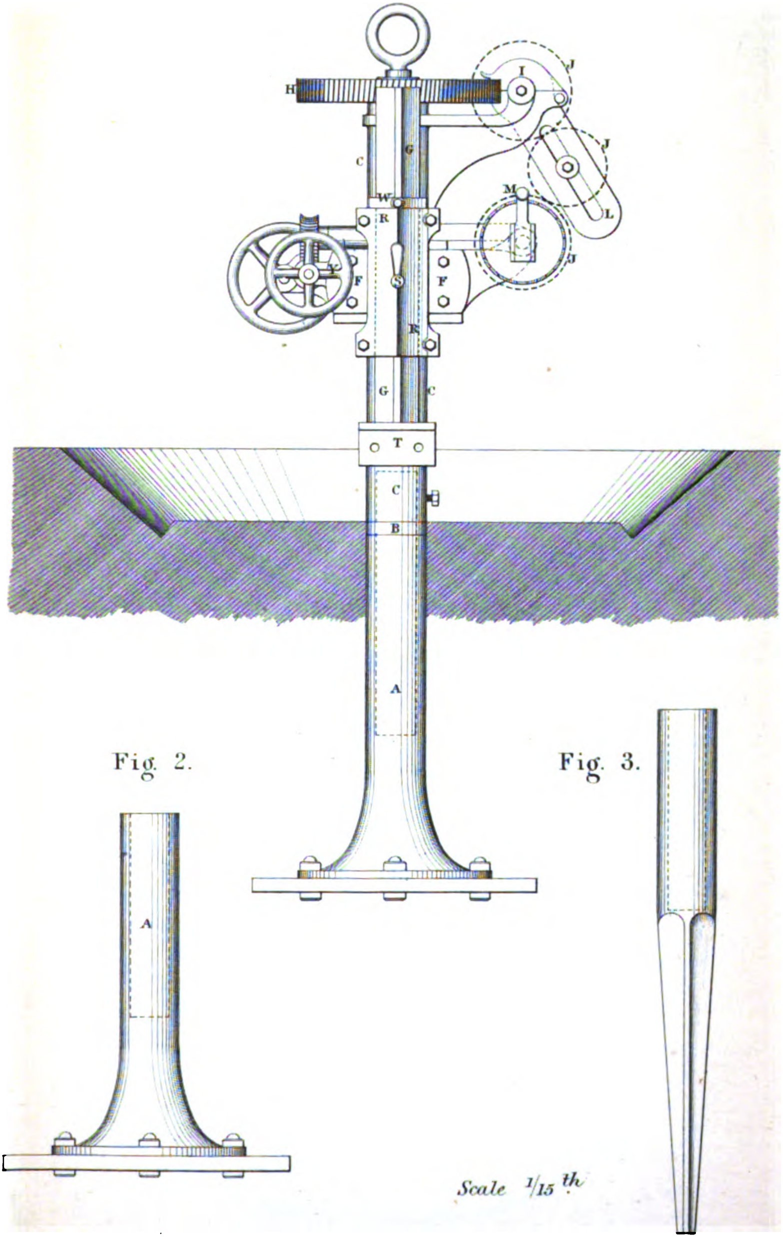


Fig. 2.

Fig. 3.

Scale $^1/_{15}$ th

(Proceedings Inst. M.E. 1868.)

WHEEL MOULDING MACHINE. *Plate 119.*

Fig. 4. *Side Elevation of Moulding Machine.*

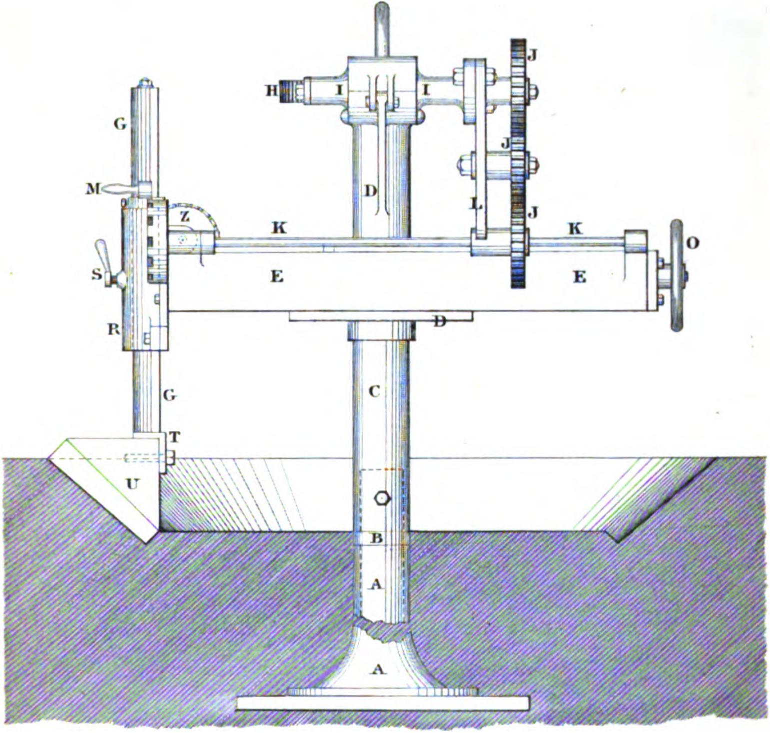
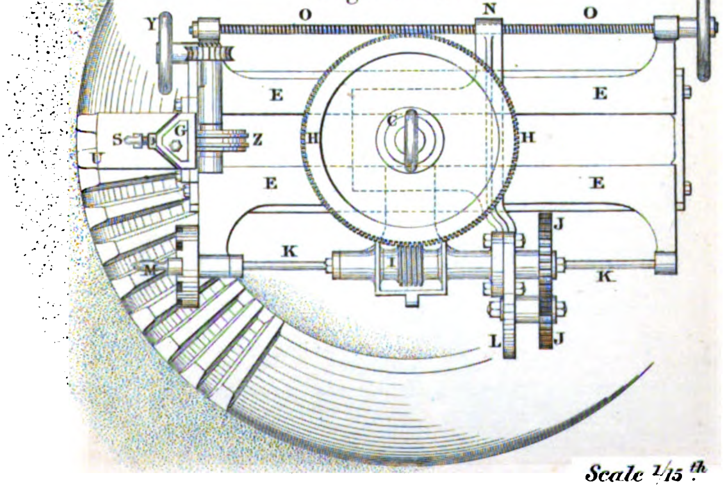


Fig. 5. *Plan.*



Scale 1/15th.

0 10 20 30 *Inches.*

(Proceedings Inst. M.E. 1868.)

WHEEL MOULDING MACHINE. *Plate 120.*

Fig. 6.

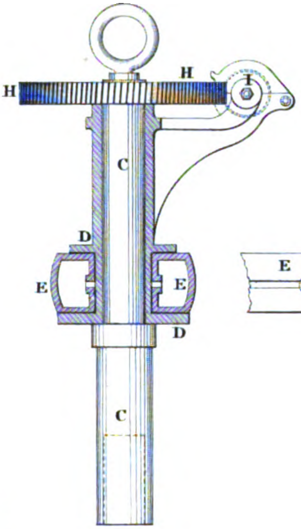


Fig. 7.

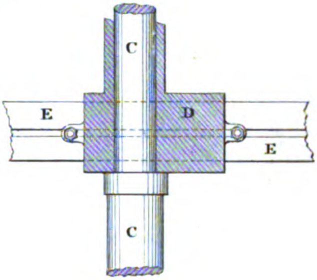


Fig. 8.

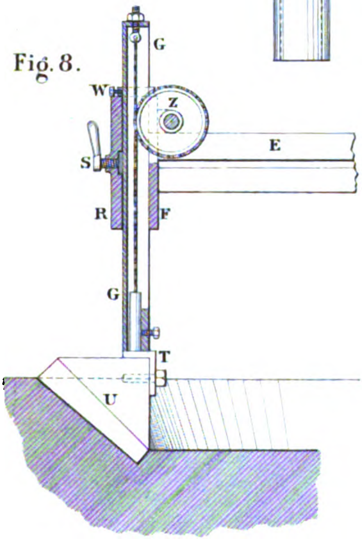


Fig. 9.

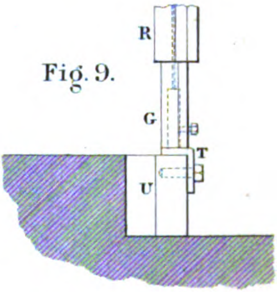


Fig. 10.

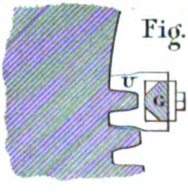
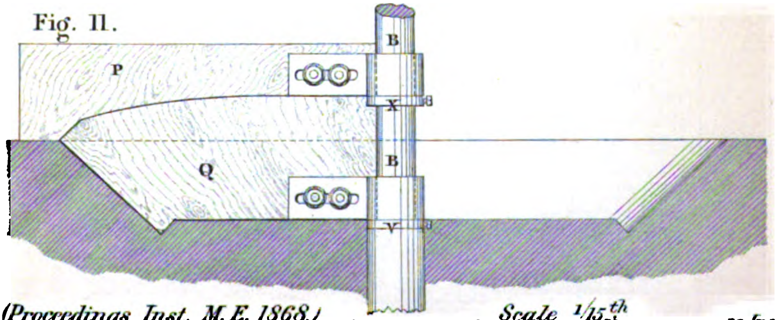


Fig. 11.



(Proceedings Inst. M.E. 1868.)

Scale 1/15th

0 10 20 30 *Ins.*

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